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Title of the Invention: MULTI-EYE IMAGING APPARATUS

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are the translators of the document attached and we state that the following is a true translation to the best of our knowledge and belief of Japanese Patent Application No. JP2005-154447 (Date of Application: 26 May 2005).

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[Document Name] CLAIMS

[Claim1]

An imaging apparatus comprising:

a plurality of optical systems;

an imaging element including a plurality of imaging regions that correspond to the plurality of optical systems in one-to-one correspondence;

a pixel shift means for relatively shifting positions of images formed on the imaging element in time series;

a memory for storing image information obtained by the imaging element;

a shake amount obtaining means for obtaining a shake amount by comparing the image information stored in the memory;

an optimal image selecting means for selecting images used for image combination from images stored in the memory; and

an image combining means for combining a plurality of pieces of image information stored in the memory,

wherein the pixel shift means does not perform a pixel shift on images formed by at least one optical system of the plurality of optical systems, but performs a pixel shift on images formed by the remaining optical systems,

the imaging element captures images in each of the plurality of imaging regions with the same timing regardless of presence or absence of the pixel shift,

the shake amount obtaining means obtains the shake amount of an image by comparing the plurality of pieces of image information captured in time series by the optical system without performing the pixel shift and stored in the memory,

the optimal image selecting means selects images used for image combination based on the shake amount obtained by the shake amount obtaining means, and

the image combining means corrects the images selected by the optimal image selecting means based on the shake amount obtained by the shake amount obtaining means, and then combines the images.

[Claim 2]

The imaging apparatus according to claim 1, further comprising a subject discriminating means for discriminating different subjects,

wherein the shake amount obtaining means obtains the shake amount of an image for each subject discriminated by the subject discriminating means, and

the optimal image selecting means selects the images used for image combination for each subject discriminated by the subject discriminating means.

[Claim 3]

The imaging apparatus according to claim 1, further comprising a block dividing means for dividing an image into a plurality of blocks,

wherein the shake amount obtaining means obtains the shake amount for each block divided by the block dividing means, and

the optimal image selecting means selects the images used for image combination for each block divided by the block dividing means.

[Claim 4]

The imaging apparatus according to claim 1, further comprising a shift amount determining means for determining a shift amount for the pixel shift,

wherein the shift amount determining means determines the shift

amount for the pixel shift for each image capture in time series based on the images selected by the optimal image selecting means and the shake amount obtained by the shake amount obtaining means, and

the pixel shift means performs the pixel shift based on the shift amount determined by the shift amount determining means.

[Claim 5]

The imaging apparatus according to claim 1, further comprising a parallax obtaining means for obtaining a parallax amount between images captured by the plurality of optical systems,

wherein the image combining means corrects the images selected by the optimal image selecting means based on the shake amount obtained by the shake amount obtaining means and the parallax amount obtained by the parallax obtaining means, and then combines the images.

[Claim 6]

The imaging apparatus according to claim 5, wherein the plurality of optical systems comprise an optical system for handling a red color, an optical system for handling a green color, and an optical system for handling a blue color, and at least one of the optical systems for handling the respective colors includes two or more optical systems,

wherein the imaging apparatus further comprises a wavelength separating means that is located on an optical axis of the optical system for handling a red color and transmits the red color, a wavelength separating means that is located on an optical axis of the optical system for handling a green color and transmits the green color, and a wavelength separating means that is located on an optical axis of the optical system for handling a blue color and transmits the blue color, and

wherein the pixel shift means does not perform a pixel shift on

images formed by at least one optical system of the two or more optical systems for handling the same color, but performs a pixel shift on images formed by the remaining optical systems.

[Claim 7]

The imaging apparatus according to claim 6, wherein each of the optical systems for handling the respective colors includes two or more optical systems, and

the pixel shift means does not perform a pixel shift on images formed by at least one optical system of the two or more optical systems for handling the respective colors, but performs a pixel shift on images formed by the remaining optical systems.

[Document Name] SPECIFICATION

[Title of the Invention] IMAGING APPARATUS

[Technical Field]

[0001]

The present invention relates to an imaging apparatus having a pixel shift function.

[Background Art]

[0002]

At present, a technique called "pixel shift" is known as a means for improving the resolution of an imaging element. FIG. 21 is a conceptual diagram for explaining how to improve the resolution using the pixel shift technique, and shows enlarged pixels of an imaging element. As illustrated in FIG. 21A, the imaging element includes an optical-to-electrical conversion portion 2101 (hereinafter referred to as an "optical-to-electrical conversion portion") which converts light into an electrical signal, and an invalid portion 2102 (hereinafter referred to as an "invalid portion"), such as a transfer electrode or the like, which cannot convert light into an electrical signal. The optical-to-electrical conversion portion and the invalid portion are combined into one pixel. In general, the pixels of the imaging element are regularly formed at predetermined intervals (pitches). A portion enclosed with a thick line in FIG. 21A is one pixel, and P indicates one pitch.

[0003]

In the pixel shift, first, an image is captured at a position of the imaging element illustrated in FIG. 21A. Next, the imaging element is shifted, e.g., in a slanting direction by 1/2 pitch of a pixel in both the horizontal direction and the vertical direction so that the optical-to-electrical conversion portion is shifted to the invalid portion for each pixel, and then

another image is captured (FIG. 21B). Thereafter, these two captured images are electrically combined, taking into consideration the shift amount of the imaging element.

[0004]

In this manner, a signal can be taken out of the invalid portion from which no signal can be inherently derived. Thus, the imaged state of FIG. 21C can be equivalent to that of an image captured by an imaging element with a double number of optical-to-electrical conversion portions, as compared to the imaged state of an image captured only once by the imaging element of FIG. 21A. Therefore, if the image is shifted as described above, an image equivalent to that captured by an imaging element having a double number of pixels can be obtained without increasing the number of pixels.

[0005]

As described above, the relative positional relationship between the light entering the imaging element and the imaging element is shifted, e.g., by 1/2 pixel, and images captured at the respective positions may be combined, resulting in a high-resolution image.

[0006]

The pixel shift is not limited to the slanting direction as described above, and the same effect can be obtained by the pixel shift in either the horizontal direction or the vertical direction. In addition to the shift by 1/2 pixel, the same effect also can be obtained by shifting the pixels so as to interpolate their invalid portions. The resolution can be improved by increasing the number of times the images are captured at different places rather than by shifting the pixels only once.

[0007]

Although, in the above-described example, the relative positional relationship between the imaging element and the incident light is changed by shifting the imaging element, the pixel shift is not limited thereto. For example, the optical lens may be moved instead of the imaging element. Alternatively, for example, another method has been proposed in which a parallel plate is employed (e.g., Patent Document 1). In the invention of Patent Document 1, the parallel plate is tilted so as to shift the optical path of image light that forms an image on the imaging element, thereby performing the pixel shift.

[0008]

When the resolution is improved by the pixel shift, a plurality of images are captured in time series and then combined to produce a high-resolution image. In the pixel shift, it is necessary to eliminate a shake caused by the movement of a photographer such as a camera shake (hereinafter referred to as a "photographer shake") and a shake caused by the movement of a subject (hereinafter referred to as a "subject shake") during capturing the plurality of images in time series.

[0009]

If a shake occurs during capturing the images, and these images are combined without any modification, the resultant image may be significantly different from the original image. Therefore, some methods for removing a shake as much as possible or correcting a shake have been proposed.

[0010]

One method is to capture an image while fixing a camera using a tripod or the like. This method can reduce the influence of a photographer shake, but cannot reduce the influence of a subject shake.

[0011]

Another method is to correct a shake with a shake detecting means. For example, the shake detecting means such as an angular velocity sensor is used to detect a photographer shake that occurs when the photographer presses a shutter release or the like, and then a shake amount is corrected based on the detected amount (e.g., Patent Document 2).

[0012]

In the invention of Patent Document 2, the pixel shift is performed by detecting a shake amount with the shake detecting means, correcting the pixel shift direction or the like based on the shake amount, and shifting the imaging element. This method can reduce the influence of a photographer shake. In addition to the method for shifting the imaging element, the same effect also can be obtained by a method for moving the optical lens or the like in accordance with the detected shake amount. However, even this method cannot detect a subject shake itself, and thus cannot reduce the influence of a subject shake.

[0013]

Yet another method is to determine a shake amount by comparing a plurality of images captured in time series and to correct a shake (e.g., Patent Document 3). In the invention of Patent Document 3, which was made by the present inventors, a shake amount is determined by comparing the plurality of images captured in time series, and a shake is corrected.

[0014]

To determine the shake amount accurately, the optical system that performs the pixel shift is separated from the optical system that does not perform the pixel shift. Then, an accurate shake amount is determined in the optical system that does not perform the pixel shift and used to correct

the shake amount in the optical system that performs the pixel shift. With this method, since both the photographer shake and the subject shake are determined as image shakes, the shake amount can be accurately determined without using the shake detecting means such as an angular velocity sensor separately. Thus, high resolution can be achieved by the pixel shift.

[Patent Document 1] JP H6-261236 A

[Patent Document 2] JP H11-225284 A

[Patent Document 3] JP 2004-363868 A

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0015]

As described above, a high-resolution image can be obtained by removing or correcting a shake in the pixel shift. In particular, the method as disclosed in Patent Document 3 is suitable for correcting the photographer shake and the subject shake simultaneously with high accuracy. However, the following problems arise when a shake is corrected after capturing the images.

[0016]

FIG. 22 is a diagram for explaining an example of a conventional pixel shift and shows enlarged pixels of an imaging element. In FIG. 22, reference numeral 2201 denotes an optical-to-electrical conversion portion and 2202 denotes an invalid portion. Hereinafter, consideration will be given to a pixel shift in which the pixels are shifted by an amount corresponding to 1/2 pixel pitch of the imaging element so as to interpolate the invalid portions. In FIG. 22, the shift amount of the pixel shift is expressed as a pixel shift vector 2203. Although the vector is indicated in

only the upper left pixel, all the pixels are shifted in the same manner. In FIG. 22, the shake amount determined during the image capture also is expressed as a shake vector. The method for determining the shake amount will be described in detail later.

[0017]

FIG. 22A shows a state in which no shake is present. Therefore, the pixel shift can be performed so as to interpolate the invalid portions of the pixels, as designed. Thus, a high-resolution image can be obtained by combining the images after the pixel shift.

[0018]

Even if a shake vector 2204 is present as shown in FIG. 22B, since the sum of the pixel shift vector 2203 and the shake vector 2204 is located in the invalid portion, a shake correction can be performed to provide pixel shift information so as to interpolate the invalid portions of the pixels. Thus, a high-resolution image can be obtained by combining the images after the pixel shift.

[0019]

However, when a shake vector 2205 is present as shown in FIG. 22C, the sum of the pixel shift vector 2203 and the shake vector 2205 is located in the optical-to-electrical conversion portion (or in the vicinity of the optical-to-electrical conversion portion) of the imaging element. Therefore, even if the shake correction is precisely performed, only the information that has been already available can be provided. Thus, a high-resolution image cannot be achieved even by the image combination.

[0020]

FIG. 23 shows an optical system that does not perform a pixel shift, and a shake is present in the optical system as in the case of FIG. 22. In

FIG. 23A, no shake is present. In FIG. 23B, a shake is present in the same amount as the vector 2204 in FIG. 22B. In FIG. 23C, a shake is present in the same amount as the vector 2205 in FIG. 22C.

[0021]

As is evident from FIG. 23C, in the optical system that does not perform the pixel shift, the invalid portions of the original pixels are interpolated by the optical-to-electrical conversion portions of the imaging element, even if the shake is present to the extent that the pixel shift is hardly effective as shown in FIG. 22C.

[0022]

Whether the shake is present as represented by the vector 2204 or the vector 2205 depends on the probability and cannot be intentionally controlled by a photographer. Therefore, when the captured images are combined after the shake correction in expectation of a high-resolution image due to the pixel shift, there is a possibility that the resultant image does not actually have such high resolution.

[0023]

The present invention is intended to solve the above conventional problems and has an object of providing an imaging apparatus that performs a pixel shift and can prevent a reduction in the effect of the pixel shift even if there is a photographer shake or a subject shake.

[Means for Solving the Problems]

[0024]

To achieve the above object, the imaging apparatus of the present invention includes the following: a plurality of optical systems; an imaging element including a plurality of imaging regions that correspond to the plurality of optical systems in one-to-one correspondence; a pixel shift

means for relatively shifting positions of images formed on the imaging element in time series; a memory for storing image information obtained by the imaging element; a shake amount obtaining means for obtaining a shake amount by comparing the image information stored in the memory; an optimal image selecting means for selecting images used for image combination from images stored in the memory; and an image combining means for combining a plurality of pieces of image information stored in the memory. The pixel shift means does not perform a pixel shift on images formed by at least one optical system of the plurality of optical systems, but performs a pixel shift on images formed by the remaining optical systems. The imaging element captures images in each of the plurality of imaging regions with the same timing regardless of presence or absence of the pixel shift. The shake amount obtaining means obtains the shake amount of an image by comparing the plurality of pieces of image information captured in time series by the optical system without performing the pixel shift and stored in the memory. The optimal image selecting means selects images used for image combination based on the shake amount obtained by the shake amount obtaining means. The image combining means corrects the images selected by the optimal image selecting means based on the shake amount obtained by the shake amount obtaining means, and then combines the images.

[Effect of the Invention]

[0025]

The present invention can prevent a reduction in the effect of the pixel shift even if a photographer shake or a subject shake is present during the pixel shift, and thus achieve a high-resolution image.

[Best Modes for Carrying Out the Invention]

[0026]

The present invention can improve the reliability of acquiring information for interpolating the invalid portions of the pixels of the imaging element, even if the photographer shake or the subject shake is present during the pixel shift. Therefore, the present invention can prevent a reduction in the effect of the pixel shift and achieve a high-resolution image.

[0027]

The imaging apparatus may further include a subject discriminating means for discriminating different subjects. It is preferable that the shake amount obtaining means obtains the shake amount of an image for each subject discriminated by the subject discriminating means, and the optimal image selecting means selects the images used for image combination for each subject discriminated by the subject discriminating means.

[0028]

With this configuration, even if the shake amount of the whole image and the shake amount of the subject are different, the shake amount can be precisely obtained, and thus the optimal images for image combination can be properly selected.

[0029]

The imaging apparatus may further include a block dividing means for dividing an image into a plurality of blocks. It is preferable that the shake amount obtaining means obtains the shake amount for each block divided by the block dividing means, and the optimal image selecting means selects the images used for image combination for each block divided by the block dividing means.

[0030]

With this configuration, the shake amount is obtained for each block, and the optimal image is also selected for each block. Therefore, the whole image can have high resolution. Moreover, if the size of the blocks is set as desired, a photographer can choose that the image combination time is reduced, or the resolution of the image is more improved in accordance with his/her intention.

[0031]

The imaging apparatus may further include a shift amount determining means for determining a shift amount for the pixel shift. It is preferable that the shift amount determining means determines the shift amount for the pixel shift for each image capture in time series based on the images selected by the optimal image selecting means and the shake amount obtained by the shake amount obtaining means, and the pixel shift means performs the pixel shift based on the shift amount determined by the shift amount determining means.

[0032]

With this configuration, the image to be selected by the optimal image selecting means can be reliably obtained, so that high resolution also can be ensured.

[0033]

The imaging apparatus may further include a parallax obtaining means for obtaining a parallax amount between images captured by the plurality of optical systems. It is preferable that the image combining means corrects the images selected by the optimal image selecting means based on the shake amount obtained by the shake amount obtaining means and the parallax amount obtained by the parallax obtaining means, and

then combines the images.

[0034]

With this configuration, even if a plurality of images captured by different optical systems and selected by the optimal image selecting means are to be combined, the image combination can be performed after correcting both the shake amount and the parallax amount. Thus, a high-resolution image can be obtained.

[0035]

It is preferable that the plurality of optical systems includes an optical system for handling a red color, an optical system for handling a green color, and an optical system for handling a blue color, and at least one of the optical systems for handling the respective colors includes two or more optical systems. The imaging apparatus may further include a wavelength separating means that is located on an optical axis of the optical system for handling a red color and transmits the red color, a wavelength separating means that is located on an optical axis of the optical system for handling a green color and transmits the green color, and a wavelength separating means that is located on an optical axis of the optical system for handling a blue color and transmits the blue color. It is also preferable that the pixel shift means does not perform a pixel shift on images formed by at least one optical system of the two or more optical systems for handling the same color, but performs a pixel shift on images formed by the remaining optical systems.

[0036]

This configuration can produce a high-resolution full color image in which both shake and parallax have been corrected.

[0037]

In this case, it is preferable that each of the optical systems for handling the respective colors includes two or more optical systems, and the pixel shift means does not perform a pixel shift on images formed by at least one optical system of the two or more optical systems for handling the respective colors, but performs a pixel shift on images formed by the remaining optical systems. This configuration can ensure the effect of the pixel shift and becomes more advantageous to high resolution.

[0038]

Hereinafter, an embodiment of the present invention will be described with reference to the accompanying drawings.

[0039]

(Embodiment 1)

FIG. 1 is a block diagram illustrating a configuration of an imaging apparatus according to Embodiment 1. A system control means 101 is a central processing unit (CPU) that controls the whole imaging apparatus. The system control means 101 controls a pixel shift means 102, a transfer means 103, a memory 107, a shake amount obtaining means 108, an optimal image selecting means 109, and an image combining means 110.

[0040]

A subject (not shown) is imaged in different regions of an imaging element 106 by imaging optical systems 104, 105, and then photoelectrically converted into image information as a light intensity distribution by the imaging element 106. The pixel shift means 102 shifts the relative position between the imaging element 106 and the subject image formed on the imaging element 106 by the imaging optical system 105. The relative position between the imaging optical system 104 and the imaging element 106 is designed not to be changed. The transfer means 103 transfers the

image information provided by the imaging element to the memory 107 that stores images.

[0041]

The images are captured at different times (in time series) while the pixel shift is performed, and image information captured using the imaging optical system 104 and pixel-shifted image information captured using the imaging optical system 105 are successively stored in the memory 107 every time the images are captured.

[0042]

The shake amount obtaining means 108 obtains a shake amount by comparing the image information captured at different times (in time series) using the imaging optical system 104, i.e., the optical system that does not perform the pixel shift. The optimal image selecting means 109 selects the optimal images for image combination based on the shake amount obtained by the shake amount obtaining means 108.

[0043]

The image combining means 110 combines the images selected by the optimal image selecting means 109 after the correction based on the shake amount obtained by the shake amount obtaining means 108, thereby producing a high-resolution image.

[0044]

FIG. 2 is a flowchart illustrating a whole operation of the imaging apparatus of this embodiment. The image capture is started by an image capture start command of step 200. When the image capture is started, an image capture preprocess of step 201 initially is performed. In this process, an optimal exposure time is calculated, and a focusing process is performed.

[0045]

For example, there is a phenomenon that if a distance between a subject and an imaging apparatus is changed, an imaging distance is changed, so that an image is blurred. To correct the phenomenon, a distance between an imaging optical system and an imaging element is adjusted (focusing). Focusing can be achieved by using a property that a captured image has a maximum contrast when a focus is obtained, and changing a space (imaging distance) between the imaging optical system and the imaging element using a focusing actuator (not shown).

[0046]

Note that contrast does not have to be used necessarily for focusing, and a distance to a subject may be measured using laser, radio wave, or the like, to perform focusing.

[0047]

Also, an optimal exposure time needs to be adjusted, taking ambient light into consideration. To this end, there are a method of detecting brightness using an illuminance sensor to set an exposure time, a method of providing a preview function that takes in an image before the start of the image capture, and the like. In the case of the method of providing the preview function, an image taken in before the start of the image capture is converted into a grayscale image (i.e., brightness information). Thereafter, if the histogram is unbalanced to a white color (bright), it is determined that exposure is excessive (excessively long exposure time), and if the histogram is unbalanced to a black color (dark), it is determined that exposure is insufficient (excessively short exposure time), and the exposure time is adjusted.

[0048]

When the preview function is possessed, by performing this

preprocess before an image capture start command, a time required from the image capture start command to the start of exposure can be reduced.

[0049]

Next, the image capture is performed in step 202. The image capture is performed by repeating the processes of steps 203 to 205. In step 203, the imaging element 106 performs a photoelectric conversion (i.e., an exposure process). In step 204, the transfer means 103 transfers an image from the imaging element 106 to the memory 107. In step 205, the pixel shift means 102 shifts the relative position between the imaging optical system 105 and the imaging element 106.

[0050]

As described above, when the images are captured at different times, a shake may occur in the images due to the photographer shake or the subject shake during each image capture. In step 206, to correct the shake, the shake amount obtaining means 108 determines a shake amount from a plurality of pieces of image information that have been captured in time series by the imaging optical system 104 and stored in the memory.

[0051]

The presence of the photographer shake and the subject shake causes the images to move. Therefore, when one of two images captured at different times is identified as a comparative reference image and the other is identified as a comparative target image, the amount of photographer shake and the amount of subject shake can be determined by examining to which part of the comparative target image a certain region of the comparative reference image is moved.

[0052]

Hereinafter, a method for determining the shake amount by image

comparison will be described. In order to examine to which region of the comparative target image a specific region of the comparative reference image (hereinafter referred to as a "comparative reference region") corresponds, an evaluation region having the same size as the comparative reference region is set in the comparative target image to evaluate how much the comparative reference region and the evaluation region resemble each other. Thereafter, evaluation regions are set successively at other positions, and the destination of the comparative reference region is searched for while performing the evaluation in each of the evaluation regions. In this case, the evaluation region that resembles the comparative reference region most is the destination of the comparative reference region.

[0053]

An image captured by the imaging element can be considered as a set of light intensities corresponding to the individual pixels. Therefore, if an upper left of the image is the origin, and the light intensity of a pixel which is an x-th pixel to the right in the horizontal direction and a y-th pixel downward in the vertical direction is represented by $I(x, y)$, the image can be assumed to be a distribution of the light intensity $I(x, y)$.

[0054]

FIG. 3 illustrates the positional relationship between a comparative reference region 301 and an evaluation region 302. In the example of FIG. 3, the comparative reference region is set to be in the shape of a rectangle which has an upper left pixel located at $(x1, y1)$ and a lower right pixel located at $(x2, y2)$. In this case, an evaluation region (m, n) shifted by m pixels in the right direction and n pixels in the downward direction from the comparative reference region can be represented by a region having an upper left pixel located at $(x1+m, y1+n)$ and a lower right pixel located at

(x2+m, y2+n).

[0055]

An evaluation value R(m, n) indicating a correlation between the evaluation region and the comparative reference region (how much they resemble each other) is represented by the sum of the absolute values of differences in light intensity between each pixel, as indicated by (Expression 1).

[0056]

[Expression 1]

$$R(m,n) = \sum_{y=y_1}^{y_2-y_1} \sum_{x=x_1}^{x_2-x_1} \left| I_1(x,y) - I_2(x+m, y+n) \right|$$

[0057]

The more the comparative reference region and the evaluation region resemble each other, the smaller the difference in light intensity between corresponding pixels in the two regions. Therefore, the evaluation value R(m, n) indicates a smaller value as the correlation between the light intensity distributions (image) of the comparative reference region and the evaluation region increases (they resembles each other to higher extent).

[0058]

In the present invention, the shake amount should be determined with an accuracy of not more than a pixel pitch of the imaging element 106 (referred to as "subpixel" in the following) so as to select the images by the optimal image selecting means 109. As a method for determining the shake amount with subpixel accuracy, data I'(x, y) is newly created by interpolating between each pixel from the original light intensity I(x, y), and based on I'(x, y), the evaluation value R(m, n) is calculated in accordance

with (Expression 1). The interpolation of data may be either linear interpolation or nonlinear interpolation.

[0059]

Thus, the shake amount is obtained by searching for the evaluation region that resembles the comparative reference region most with subpixel accuracy while changing the values of m and n. In this case, since the shake directions of the photographer shake and the subject shake are not limited to specific directions, negative values also need to be studied for the values of m and n (evaluation of regions shifted in the left direction or in the upward direction).

[0060]

m and n may be changed so that the whole range of the comparative target image can be evaluated. However, when the image of a subject is moved significantly due to an apparatus shake, so that the image is departed from the light receiving range of the imaging element, the subject cannot be combined as an image. Therefore, in general, it is preferable that m and n be limited to a predetermined range, thereby reducing a calculation time. A combination of m and n thus found that minimizes the evaluation value R(m, n) is a shake amount indicating the position of a region of a comparative target image corresponding to the comparative reference region.

[0061]

Note that the comparative reference region is not necessarily limited to rectangles, and can be set to be in any arbitrary shape. Also, the calculation of the evaluation value is not necessarily limited to the sum of the absolute values of differences in light intensity. Any function indicating the correlation (e.g., normalization is performed for each region

before obtaining the correlation, etc.) may be used to calculate the evaluation value.

[0062]

Next, in step 207, the optimal image selecting means 109 selects the optimal images for image combination based on the shake amount obtained by the shake amount obtaining means 108. The method for selecting the optimal images can be determined by user's setting. As one possible method, the shake amount obtained by the shake amount obtaining means 108 may be expressed as a shake vector 401, as shown in FIG. 4A. In this case, the shake vector 401 is divided into a vector 402 and a vector 403. The vector 402 extends to the optical-to-electrical conversion portion that is closest to the end point of the shake vector 401 and the vector 403 extends from the closest optical-to-electrical conversion portion to the end point of the shake vector 401.

[0063]

FIG. 4B is an enlarged view showing a pixel including the vector 403 and other pixels around this pixel. Reference numeral 404 denotes a region of 1/4 pixel pitch that has the base point of a pixel pitch as a center and is aligned in both vertical and horizontal directions. Reference numeral 405 denotes a region of 1/2 pixel pitch that has the base point of a pixel pitch as a center and is aligned in both vertical and horizontal directions.

[0064]

In this embodiment, when the absolute value of the vector 403 is in the range of 0 to 1/4 pixel pitch, the images captured by the optical system 105 that performs the pixel shift are selected. When the shake amount is in the range of 1/4 to 1/2 pixel pitch, the images captured by the optical system 104 that does not perform the pixel shift are selected. This ensures

the image information for interpolating the invalid portions of the images that are captured before a shake occurs. On the other hand, if a single imaging optical system is used, whether or not such image information for interpolating the invalid portions can be obtained depends on the probability, and thus the reliability becomes poor.

[0065]

In the example of FIG. 4, since the shake vector 403 is in the range of 1/4 to 1/2 pixel pitch, the optimal image selecting means 109 selects the images of the optical system 104 that does not perform the pixel shift.

[0066]

In this embodiment, although the optical images are selected based on the pixel pitch in the vertical and horizontal directions of the imaging element, the pixel pitch in the slanting direction also may be used. Moreover, some references of the pixel pitch may be used together according to the circumstances.

[0067]

Next, in step 208, the images that have been stored in the memory 107 and selected by the optimal image selecting means 109 are corrected based on the shake amount determined in step 206 and then combined, thereby producing a high-resolution image.

[0068]

FIG. 5 is a conceptual diagram of a method for correcting the shake amount. Images 501 to 504 are stored in the memory and captured at two different times (referred to as "image capture time 1" and "image capture time 2" in the following) by the imaging optical system 104 and the imaging optical system 105.

[0069]

The image 501 is captured by the imaging optical system 104 at the image capture time 1. The image 502 is captured by the imaging optical system 105 at the image capture time 1. The image 503 is captured by the imaging optical system 104 at the image capture time 2. The image 504 is captured by the imaging optical system 105 at the image capture time 2. A region 501a is within the image 501. In the image 502, a region 502a contains the same image as the subject image present in the region 501a.

[0070]

In the image 503 captured at the image capture time 2, the subject image present in the region 501a is moved to a region 503c. A vector 503b is a difference between the region 503c and a region 503a that is located at the original position of the region 503c (i.e., the same position as the region 501a), and indicates the shake amount of the region 501a due to the photographer shake or the subject shake.

[0071]

Similarly, in the image 504 captured at the image capture time 2, the subject image present in the region 502a is moved to a region 504e. Since the pixel shift is performed on the image 504, a vector 504f is a difference between the region 504e and a region 504a that is located at the original position of the region 504e (i.e., the same position as the region 502a). Moreover, the vector 504f is the sum of a vector 504b that indicates the shake amount due to the photographer shake or the subject shake and a vector 504d that is intentionally shifted by the pixel shift.

[0072]

In the case of a normal pixel shift, the image 504e is to be combined. Therefore, the image (504c) that is initially supposed to be extracted cannot be precisely extracted. Thus, the image is degraded.

[0073]

However, the timing of the image capture is the same in both the imaging optical system 104 and the imaging optical system 105. Therefore, there is no difference in the shake amount due to the photographer shake or the subject shake between the image 503 and the image 504 (i.e., the vector 503b and the vector 504b are equal). Accordingly, when the shake amount (vector 503b) derived from the images 501, 503 is taken into account in performing the pixel shift and the image combination, the images can be properly combined. Thus, a high-resolution image can be obtained.

[0074]

As described above, the optical system that does not perform the pixel shift is allowed to capture an image at the same time as the image capture by the optical system while it performs the pixel shift. Using this image as a reference, a shake such as the photographer shake or the subject shake can be precisely corrected.

[0075]

The images that have been selected by the optimal image selecting means 109 and stored in the memory 107 are corrected with the above correction method, and then combined by the image combining means 110, so that a high-resolution image can be produced without any degradation of the image.

Finally, in step 209, the combined image is output, and a series of image capture operations is ended. Hereinafter, Embodiment 1 will be described more specifically by way of the following examples.

[0076]

(Example 1)

FIG. 6 shows a configuration including the imaging optical system,

the pixel shift means, and the imaging element of this example. As the imaging optical system, two aspherical lenses 601a and 601b, each having a diameter of 3 mm, were used. The optical axes of the lenses are substantially parallel to the Z-axis in FIG. 6.

[0077]

A glass plate 602 was located on the optical axis of the lens 601b and tilted by a piezoelectric actuator and a tilting mechanism. With this configuration, the pixel shift was performed. The piezoelectric actuator and the tilting mechanism are not shown in FIG. 6. As the glass plate 602, an optical glass BK7 having a width (X-axis direction in FIG. 6) of 1 cm, a height (Y-axis direction in FIG. 6) of 1 cm, and a thickness (Z-axis direction in FIG. 6) of 500 μm was used.

[0078]

As an imaging element 603, a black-and-white CCD 603 was used in which a pitch between adjacent pixels was 2.4 μm. The glass plate 602 and the imaging element 603 had light receiving surfaces that were substantially parallel to the XY plane of FIG. 6. Also, the imaging element 603 was divided into two regions 603a and 603b, which corresponded to the respective optical systems in one-to-one correspondence. To perform the pixel shift by 1/2 (1.2 μm) of a pixel pitch, the glass plate should be tilted at about 0.4 degrees. In this configuration, an image obtained after one-time pixel shift, which allowed the pixels to be shifted to the invalid potions of the imaging element, and the original image were combined into an image.

[0079]

FIG. 7 shows images stored in the memory with this configuration. The time when a first image was captured is referred to as image capture time 1 and the time when a second image was captured after the pixel shift

(after the glass plate was tilted) is referred to as image capture time 2.

[0080]

Images 701 and 702 were captured through the lenses 601a and 601b at the image capture time 1, respectively. An image 703 was captured through the lens 601a (i.e., the optical system that did not perform the pixel shift) at the image capture time 2. An image 704 was captured through the lens 601b (i.e., the optical system that performed the pixel shift) at the image capture time 2.

[0081]

In this example, a scene in which the motion of a subject is sufficiently small (e.g., a landscape, etc.) was captured. Therefore, there was no subject shake between the image 701 captured at the image capture time 1 and the image 703 captured at the image capture time 2. If a shake was present, it could be assumed that the whole image was moved due to the photographer shake.

[0082]

In this case, since the whole image was uniformly moved under certain conditions, the shake amount could be determined only by evaluating to which region of the image 703 (captured at the image capture time 2 by the optical system that did not perform the pixel shift) the central portion (e.g., a region of 100 × 100 pixels) of the image 701 (captured at the image capture time 1 by the same optical system) was moved, using an image comparing method with (Expression 1). The size of the region to be compared may be set as desired.

[0083]

Based on this shake amount, the images were selected by the optimal image selecting means 109 for image combination. In this example,

the optimal images were selected by the method as described with reference to FIG. 4. The absolute value of the shake amount corresponding to the vector 403 in FIG. 4 was 0.1 pixel pitch. Therefore, the images captured by the optical system that performed the pixel shift were selected in this example.

[0084]

Next, the image 704 captured by the optical system that performed the pixel shift was corrected based on the above shake amount, and then combined with the image 702, resulting in a high-resolution image.

[0085]

In this example, although a method for tilting the glass plate was used as the pixel shift means, the pixel shift means is not limited to this method. For example, an actuator including a piezoelectric element, an electromagnetic actuator, or the like may be used to physically move the imaging element or the lenses in a predetermined amount.

[0086]

In this example, the glass plate was not provided for the optical system that did not perform the pixel shift. However, if the glass plate is provided so as not to be tilted, the pixel shift will not be performed. Such a configuration can increase the degree of freedom in deciding whether or not to perform the pixel shift, as compared to the case where the pixel shift means is excluded from the beginning.

[0087]

The same configuration may be applied to the pixel shift using any methods other than the glass plate. For example, if the pixel shift means is an actuator including a piezoelectric element, the pixel shift can be avoided by intentionally keeping the actuator from moving, although the actuator

may be excluded from the beginning so that the pixel shift is not performed.

[0088]

Like the parallel plate as described above, this case also increases the degree of freedom in deciding whether or not to perform the pixel shift, compared to the case where the pixel shift means is excluded from the beginning.

[0089]

In this example, although one imaging element was divided into two regions, two different imaging elements may be used for the respective optical systems in one-to-one correspondence. Any form of the imaging element may be used as long as a plurality of imaging regions correspond to the respective optical systems in one-to-one correspondence.

[0090]

FIG. 8 is a conceptual diagram of the photographer shake. FIG. 8A is a diagram illustrating the case where a subject and a camera are translated, and A of FIG. 8C shows a change between images at the image capture times 1 and 2. FIG. 8B is a diagram illustrating the case where the camera is horizontally rotated, and B of FIG. 8C shows a change between images at the image capture times 1 and 2.

[0091]

As can be seen from FIG. 8C, the influence of the photographer shake on the images is larger when the optical axis deviates due to the horizontal rotation of the camera, as shown in FIG. 8B, than when the subject and the camera are translated, as shown in FIG. 8A. FIG. 8B shows an example in which the camera is horizontally rotated, and the same is true for the camera to be vertically rotated.

[0092]

In the case of rotation, since the distance between the subject and the lens is partially changed, a slight distortion occurs in the image. If the slightly distorted images are simply superimposed, portions that should coincide with each other do not coincide with each other, so that the effect of improving the resolution cannot be obtained even by the pixel shift.

[0093]

Therefore, the image distortion caused by the rotation needs to be detected and corrected. In the method of Example 1, the amount of photographer shake is determined in one specific evaluation region. However, if a plurality of evaluation regions are set, and the shake amount is determined in each of the evaluation regions, the amount of photographer shake and the image distortion can be obtained in each of the evaluation regions. At least two evaluation regions are required to detect the image distortion. By deforming the images to be superimposed in accordance with the image distortion, it is possible to prevent the degradation of the images and to produce a high-resolution image.

[0094]

(Example 2)

Example 2 is different from Example 1 in that there is a shift amount of a subject whose image is to be captured (e.g., a human, an animal, etc.). In Example 2, a scene is captured in which a subject moves to another place during a time from capturing of a first image until the data is stored into a memory and a second image is captured, so that a portion of the subject moves to another place between the first image and the second image.

[0095]

The basic configuration of Example 2 is similar to that of Example 1,

and the overlapping portions will not be described. When a subject moves significantly, the whole image is not uniformly moved under certain conditions. Therefore, unlike Example 1, the whole movement cannot be estimated from the movement of some regions of the image.

[0096]

Therefore, in Example 2, a block dividing means is provided for dividing an image into a plurality of blocks, and a shake amount is determined for each block. The block dividing means is controlled by the system control means 101 and divides the whole of a first image captured by the optical system that does not perform the pixel shift into blocks having 10×10 pixels. The shake amount obtaining means 108 examines to which position of a second image each of the blocks of the first image corresponds. The shift amount of the image was obtained by (Expression 1).

[0097]

FIG. 9 shows the images stored in the memory in Example 2. FIG. 9A illustrates an image captured at the image capture time 1. FIG. 9B illustrates an image captured at the image capture time 2 by the optical system that did not perform the pixel shift. FIG. 9C illustrates a shift amount of an image obtained for each block.

[0098]

In FIG. 9C, A represents a block for which a shake of 10.1 pixels in the right direction was obtained in FIG. 9A, and B represents a block in which a shake of 8.8 pixels in the left direction was obtained in FIG. 9A. FIG. 9 does not include a drawing that corresponds a detailed shake amount.

[0099]

Next, the optimal image selecting means 109 selected the images for

image combination. The images were selected in the same manner as Example 1. For the blocks represented by A in FIG. 9, the absolute value of the amount corresponding to the vector 403 in FIG. 4 was 0.1 pixel pitch. Therefore, the images captured by the optical system that performed the pixel shift were selected.

[0100]

For the blocks represented by B in FIG. 9C, the absolute value of the amount corresponding to the vector 403 in FIG. 4 was 0.2 pixel pitch. Therefore, the images captured by the optical system that performed the pixel shift were selected.

[0101]

As described above, when the image is divided into blocks, and the movement is recognized for each block, distributions of the shake amounts due to the photographer shake and the subject shake can be separately obtained. Moreover, the optimal images for image combination can be selected based on the shake amount in each block.

[0102]

Moreover, by setting the size of the blocks divided by the block dividing means as desired, the optical image combination can be achieved in accordance with the intention of a photographer. For example, if the image is divided into large blocks, the time required for image combination can be reduced. On the contrary, if the image is divided into small blocks, the shake amount can be determined in detail for each block, and thus the combined image has higher resolution.

[0103]

Next, the images selected by the optimal image selecting means were corrected based on the shake amount in each block obtained by the

shake amount obtaining means 108 and then combined, so that a high-resolution image was produced even if the subject moved significantly.

[0104]

Note that image processing may be performed in accordance with the selection by the user so that only the photographer shake is corrected and the subject shake is intentionally not corrected, thereby making it possible to provide a correction mode in which the dynamism of a scene having a motion is emphasized.

[0105]

In Example 2, all the images selected by the optimal image selecting means were captured by the same optical system. Therefore, the images captured by the same optical system were combined after only the correction based on the shake amount. However, depending on the absolute value of the amount corresponding to the vector 403 in FIG. 4, the images captured by the other optical system that performed the pixel shift could be selected. In other words, the images selected by the optimal image selecting means 109 may differ in the optical system from block to block.

[0106]

A parallax may occur between the images captured by different optical systems, as will be described in Embodiment 2. The parallax can be corrected by a configuration of Embodiment 2, which will be described later. Thus, even if the images captured by different optical systems are selected, those images can be combined after correcting the parallax, thereby producing a high-resolution image.

[0107]

If the subject shake is present, there may be an occluded portion of the subject in the images after the pixel shift (i.e., the block indicated by "×"

in FIG. 9C). In such a case, only the image captured at a specific time may be selected without combining the images after the pixel shift for that portion.

[0108]

If a user selects blocks that will probably move and blocks that will not probably move before the image capture, the calculation cost of the shake amount after the image capture can be reduced.

[0109]

(Example 3)

Example 3 is different from Examples 1, 2 in that a subject discriminating means for discriminating different subjects in an image is provided. By using the subject discriminating means, the shake amount can be easily obtained for each subject. Therefore, even when there are different shake amounts in an image, e.g., when not only the photographer shake but also the subject shake is present, the shake amounts can be precisely obtained.

[0110]

As described in Example 2, when the shake amount is determined by dividing the image into blocks, the division of the image into blocks can be performed for each subject, or the size of the blocks can be changed for each subject. For the image combination, the images may be combined selectively only for a specific subject.

[0111]

Examples of the subject discriminating means include a means for measuring a distance to a subject using radio wave to identify different image regions and a means for performing edge detection or the like using image processing to discriminate different subjects. The subject

discriminating means is not limited thereto. Any specific means can be used as long as different subjects in an image can be discriminated. The basic configuration of Example 3 is similar to that of Example 1, and overlapping portions will not be described.

[0112]

FIG. 10 is a diagram illustrating a captured image and subject groups discriminated by the subject discriminating means in Example 3. In Example 3, the captured image was divided into blocks having 10×10 pixels (11 (width) × 9 (length)), and a distance to a subject was measured using radio wave for each block to discriminate different subjects. In the subject discrimination, subjects having a measured distance within a certain error range were discriminated as the same subject. In Example 3, the error range was 5%.

[0113]

FIG. 10A illustrates an image captured at the image capture time 1. FIG. 10B illustrates an image captured at the image capture time 2 without performing the pixel shift. Also, a distance (unit: meter) measured using radio wave is indicated for each block.

[0114]

Before the image capture at the image capture time 1, a distance to a subject was measured using radio wave. As a result, as illustrated in FIG. 10A, two subject groups were discriminated roughly. One is a subject group 1 at a distance of about 5 meters, and the other is a subject group 2 at a distance of about 2 meters. Each subject group is discriminated as falling within the above-described error range of 5%.

[0115]

Before the image capture at the image capture time 2, a distance to

a subject was measured using radio wave. As a result, subject groups were discriminated as illustrated in FIG. 10B. In Example 3, the shake amounts before and after pixel shift were obtained for each subject group.

[0116]

By using the shake amount obtaining means 108, the shake amount was obtained for each subject group. As a result, regarding the subject group 1, a shake of 10.3 pixel pitch in the left direction was obtained in FIG. 10. This shake is illustrated as a 1-block shake in FIG. 10. Regarding the subject group 2, there is a large subject shake, and a portion of the subject group 2 is out of the image, so that the shake amount of the whole subject group was not precisely obtained.

[0117]

Therefore, in Example 3, in the image captured at the image capture time 2, the shake correction was performed only on the subject group 1 before image combination. The images were selected by the optimal image selecting means 109 in the same manner as Example 1.

[0118]

The absolute value of the amount corresponding to the vector 403 in FIG. 4 was 0.3 pixel pitch. Therefore, the optimal image selecting means 109 selected the images captured by the optical system that did not perform the pixel shift. In the subject group 1, the images selected by the optimal image selecting means 109 were combined. In the other portions, images were produced using the images captured at the image capture time 1 by the optical system that did not perform the pixel shift.

[0119]

As described in Example 3, by discriminating different subjects using the subject discriminating means, the shake amount can be obtained

for each subject, and thus the shake amount of an image can be precisely corrected.

[0120]

When a portion of an image is out of the image capture range due to the photographer shake and the subject shake so that the image cannot be recognized, the improvement of the resolution due to pixel shift is not performed in the image region, and one of a plurality of captured images may be selected.

[0121]

(Embodiment 2)

Embodiment 2 is different from Embodiment 1 in that images to be combined are captured by different optical systems. When the images to be combined are captured by the same optical system, these images are subjected to shake correction and then combined, whereby a high-resolution image was obtained.

[0122]

However, when the images to be combined are captured by different optical systems, a parallax occurs because the optical systems are different. The present embodiment is to correct the parallax when the images to be combined are captured by different optical systems. Hereinafter, an explanation will be given with reference to examples.

[0123]

(Example 4)

FIG. 11 illustrates a configuration of an imaging optical system, a pixel shift means, and an imaging element according to Example 4. As imaging optical systems, aspherical lenses 1101a to 1101d each having a diameter of 3 mm are used. Each lens has an optical axis substantially

parallel to a Z axis in FIG. 11. Color filters 1102a to 1102d are provided before the respective lenses (on the subject side) as wavelength separating means that transmit only specific wavelengths. 1102a and 1102d indicate color filters which transmit a green color, 1102b indicates a color filter which transmits a red color, and 1102c indicates a color filter which transmits a blue color. 1103a to 1103d indicate four imaging elements corresponding to the respective lenses in one-to-one correspondence, and are configured to receive only specific color components. By combining images formed by the optical systems (color components), a color image can be produced.

[0124]

The imaging element has a pixel pitch of 3 μm in this example. The lens and the imaging elements are each provided parallel to an X axis in FIG. 11 and are equally spaced, and each imaging element has a light receiving surface parallel to the XY plane in FIG. 11. 1104 indicates a piezoelectric small movement mechanism that serves as a pixel shift means.

[0125]

The imaging elements 1103a to 1103c are attached to the piezoelectric small movement mechanism so that the imaging elements 1103a to 1103c are driven in the X direction and the Y direction in FIG. 11. 1103d is separated from the piezoelectric small movement mechanism, and is configured not to perform pixel shift.

[0126]

FIG. 12 is a top view of the piezoelectric small movement mechanism. The imaging elements are provided on a stage 1201 at a center portion. The stage 1201 is moved finely in the X-axis direction of FIG. 12 using laminated piezoelectric elements 1202a and 1202b, and a stage fixing frame 1202 is moved finely in the Y-axis direction of FIG. 12

using laminated piezoelectric elements 1203a to 1203d. Thereby, the imaging element can be moved finely separately in two axial directions orthogonal to each other in a horizontal plane of the imaging element.

[0127]

In this example, by one image capture command, four images were captured while performing pixel shift. The imaging elements were configured to perform image capture while being shifted by a 1/2-pixel pitch (1.5 μm) in each of the X direction and the Y direction. Specifically, an image capture was performed without pixel shift (first image), and then the imaging elements were shifted by a 1/2 pitch in the X direction to perform an image capture (second image). Next, the imaging elements were shifted by a 1/2 pitch in the Y direction while keeping the X-direction position to perform an image capture (third image). Finally, the imaging elements were moved by a -1/2 pitch in the X direction while keeping the Y-direction position to perform an image capture (fourth image). By combining these four images, a high-resolution image was obtained.

[0128]

From a plurality of images captured in time series using the imaging optical system 1101d that does not perform pixel shift, shake amounts at respective image capture times were obtained. Based on the obtained shake amounts, the optimal image selecting means 109 selected images captured by the optical system that performs pixel shift. A method illustrated in FIG. 4 was used as a method of selecting images. With respect to the images, each of which is captured by performing the pixel shift using the imaging optical systems 1101a, 1101b, and 1101c each corresponding to green, red, and blue colors, a shake correction was performed for each. In the imaging apparatus of present example, as will

be described later, after parallax amounts are corrected for the images captured at the same time by the different imaging optical systems 1101a to 1101c, the images are combined, thereby producing a full-color image.

[0129]

In addition, if the image has a different shake amount, the image selected by the optimal image selecting means 109 may possibly be an image captured by the imaging optical system 1101d that does not perform pixel shift. The present example does not include an imaging optical system that does not perform pixel shift and corresponds to red and blue colors. Accordingly, it is possible that a color is created for an optical system other than the existing optical system through calculation to be combined.

[0130]

Also, it is possible that an image of the optical system that performs pixel shift is selected regardless of the shake amount. In such a case, the effect of pixel shift may be reduced depending on a shake amount but it will not be significantly disadvantageous in correcting the shake amount.

[0131]

If an imaging optical system that does not perform pixel shift is provided for each of all green, red and blue colors, high-resolution image can be obtained reliably even if images selected by the optimal image selecting means 109 are of the imaging optical system that does not perform pixel shift.

[0132]

Next, when an image of a subject is captured by different optical systems, the relative position of subject images formed on the imaging element varies (parallax occurs) depending on a distance to the subject.

[0133]

Hereinafter, a parallax will be explained with reference to FIG. 13. For the sake of simplicity, two imaging optical systems 1301a and 1301b having the same characteristics are provided at locations separated from each other by a distance D, and have image formation surfaces 1302a and 1302b, respectively. In this case, the imaging optical systems 1301a and 1301b observe the same subject from different positions. Therefore, a parallax occurs between images formed on the image formation surfaces 1302a and 1302b.

[0134]

A parallax amount Δ is given by (expression 2). D indicates an interval between an optical axis of the imaging optical system 1301a and an optical axis of the imaging optical system 1301b, f indicates a focal length of the imaging optical systems 1301a and 1301b, and A indicates a distance between a subject and the imaging optical systems 1301a and 1301b.

[0135]

[Expression 2]

$$\Delta = D \cdot f / (A - f)$$

[0136]

When A is sufficiently large so that the subject is assumed to be located at infinity, the parallax amount Δ can be represented by D·f/A, and Δ can be assumed to be 0. In this case, images captured by the imaging optical systems 1301a and 1301b can be assumed to be the same. Therefore, the images can be combined as they are.

[0137]

However, if A is small, the parallax amount Δ is a finite value and is not negligible. Specifically, the images captured by the imaging optical

system 1301a and the imaging optical system 1301b have a difference due to a parallax, depending on the distance to a subject, and cannot be assumed to be the same. Therefore, the images cannot be superposed and combined as they are.

[0138]

In order to correct the parallax, an image capture with pixel shift is performed four times. The images captured first time by the lenses 1101a and 1101d are divided into square blocks having 24×24 pixels. The images are compared and shift amount (parallax amount) is obtained using (expression 1) in the same manner as in obtaining shake amount as mentioned above. In this case, if the square blocks for an image captured by the lens 1101a is set to be a comparative reference region, then the square blocks for an image captured by the lens 1101d is set to be an evaluation region.

[0139]

A method of dividing into blocks is not limited to this, and the number of pixels or the shape of each divided block may be changed.

[0140]

As is different from the obtaining of a shake, a direction in which a parallax occurs is limited to a linear direction connecting the origins of the imaging elements (intersections of the imaging elements and the optical axes of the respective corresponding optical systems), and therefore, when a parallax is detected, a combination of m and n in (expression 1) may be limited, depending on the direction.

[0141]

A distance A, a distance to the subject, is obtained at the same time based on the obtained parallax amount. With respect to the images

captured by the rest of the lenses 1101b and 1101c, the correction can be carried out by calculating a parallax amount from a distance to the position of the imaging optical systems. In this example, the lens and the imaging elements are both equally spaced.

[0142]

Accordingly, in (expression 2), a value of D between the lenses 1101a and 1101b and a value of D between the lenses 1101a and 1101c correspond to 1/3 and 2/3 of a value of D between the lenses 1101a and 1101d, respectively. Therefore, the parallax amount in each of the optical systems 1101b and 1101c corresponds to 1/3 and 2/3 of the parallax amount between the lenses 1101a and 1101d, respectively.

[0143]

A shake amount is corrected with respect to each of the images captured with pixel shift as mentioned above, and the images that correspond to the respective colors (the images captured in time series by the same optical system) are combined for each color, whereby a high-resolution single color image can be obtained for the three colors.

[0144]

Next, when high-resolution single color images corresponding to each color (the images captured by the different optical systems) are combined, parallaxes occurred between the high resolution single color images are corrected based on a parallax amount obtained by the parallax obtaining means as mentioned above. Then, by carrying out a combination process with respect to the high-resolution single color images for the three colors, a full-color image of high resolution can be obtained.

[0145]

The order of combining images is not limited to the above-mentioned

order. For instance, images of different color optical systems captured by performing pixel shift at the same time (for example, image capture time 1) are combined after the parallax correction, producing a full-color image. Next, the produced full-color image is stored into a memory. Then, images of different color optical systems captured by performing pixel shift at a different time (for example, image capture time 2) are combined similarly, so that a full-color image is obtained to be stored into a memory. The full-color images stored into the memory on the pixel shift basis (on the variant time basis) are combined eventually, thereby a full-color image of high resolution is obtained.

[0146]

The parallax amount obtained in this way allows accurate correction of images when the images of different optical systems are combined, and these images corrected are combined respectively. This results in a color image of high resolution to be produced.

[0147]

In addition, it is not necessary to arrange the four optical systems to be aligned. FIG. 14A shows another example in arranging the four optical systems. In this example in FIG. 14A, the four optical systems are provided to form a rectangle. G0 and G1 represent green, R represents red, and B represents blue.

[0148] In this case, for obtaining of a parallax amount, parallaxes of the green imaging systems that are diagonally provided are used. Parallax amounts of the remaining red-color and blue-color optical systems are orthogonal components of the parallax amount of the green optical system previously obtained since the optical systems are provided to substantially form a rectangle as shown in the figure (see FIG. 14B).

[0149] Although, in this example, the color filter is provided before the lens to separate a wavelength, the color filter may be provided between the lens and the imaging element, or the color filter may be formed directly on the lens.

[0150]

The color filters are not necessarily limited to the three primary colors R, G and B. Complementary color filters may be used to separate wavelengths, and color information may be reversed and combined by image processing.

[0151]

The wavelength separating means is not limited to color filters. For example, when a glass plate is used as the pixel shift means and a mechanism of tilting the glass plate is used, a colored glass may be used as the glass plate. Thus, any specific means may be used as the wavelength separating means as long as it is a means for separating a predetermined wavelength component.

[0152]

Furthermore, the present example provides information on the distance to a subject by calculation of parallax. This makes it possible to discriminate a subject within an image as described in Example 3. In other words, a distance obtained from a parallax discriminating means can be used for a subject discriminating means. Accordingly, by obtaining a shake in an image for each of the discriminated subjects, a shake amount can be obtained more specifically.

[0153]

Although it has been described as an example that images captured by the optical system handling a green color are compared to obtain parallax

and shake amounts, the color is not necessarily limited to green and it is possible to obtain a similar effect in any color.

[0154]

Furthermore, as mentioned above, the optical system that does not perform pixel shift may be provided to correspond to any of the color components so as to improve a resolution. In such a case, obtaining of shake amount also can be reliable. For instance, in a case where there is a subject shake in a fully blue-colored substance, when a shake amount is obtained only by the optical system handling a green color, information on the blue-colored substance is lost owing to a wavelength separating means and thus, a shake amount cannot be obtained. At the same time, the optical system that does not perform pixel shift is provided to correspond to any of the color components, so that a comparison between shake amounts for each color component is possible. This prevents the information loss on the shake amount and provides further reliable shake correction.

[0155]

Also, in this example, it may be possible that a filter 1102d is provided on an optical axis of the lens 1101d when a parallax correction is performed and a filter 1102d is provided off the optical axis of the lens 1101d when a pixel shift is performed. With such a configuration, two images of green color that are assumed to be completely identical at the parallax correction are to be compared. Therefore, parallax can be obtained with high precision.

[0156]

At the pixel shift, the removal of filter causes imaging elements that correspond to the respective optical systems to be equivalent to imaging elements of monochrome images. With this configuration, even there is a

subject shake in a fully blue-colored substance, for example, the shake is obtained as luminance information, whereby the accurate shake correction can be performed.

[0157]

(Embodiment 3)

Embodiment 3 is different from Embodiments 1 and 2 in that a shift amount determining means for determining a shift amount for a pixel shift is used. Accordingly, a flowchart of image capture in the present embodiment is also different from those of Embodiments 1 and 2.

[0158]

According to a flowchart of FIG. 2 as described in Embodiment 1, when an image capture for a pixel shift is finished, the captured images are compared to obtain a shake amount. Then, optimal images for performing a combination of images are selected by an optimal image selecting means 109. In this embodiment, a shift amount for pixel shift is determined by the shift amount determining means before a pixel shift is performed. Thus, a flowchart as shown in FIG. 15 is used rather than a flowchart in FIG. 2.

[0159]

Hereinafter, the present embodiment will be described in accordance with FIG. 15. A basic configuration of the imaging apparatus is similar to that in Embodiment 1 or Embodiment 2, and the shift amount determining means will not be described in a description using FIG. 1.

[0160]

Since steps 1500 and 1501 are similar to steps 200 and 201 of FIG. 2 as described in Embodiment 1, they will not be described. Next, in step 1502, an image capture is performed. Step 1502 includes steps 1503 to

1508 as one unit.

[0161]

Steps 1503 and 1504 are similar to steps 203 and 204 of FIG. 2 as described in Embodiment 1. In step 1505, images captured by a system that does not perform pixel shift and stored into a memory are compared to obtain a shake amount. As described in Embodiment 1, a shake amount may be obtained block by block or from an entire image. A shake amount may also be obtained for each subject.

[0162]

In step 1506, the optimal image selecting means selects the optimal image for combining of images based on the obtained shake amount. For a method for selecting the optimal image, a method described in Embodiment 1 with reference to FIG. 4 can be used. In step 1507, shift amounts for performing subsequent pixel shift are determined based on the shake amount obtained in step 1505 and the image selected in step 1506.

[0163]

In step 1508, a pixel shift is performed by a pixel shift means 102 based on the shift amount determined in step 1507. Hereinafter, a series of steps in step 1502 are performed repeatedly until a predetermined number of times is finished. When the image capture is finished, in step 1509, a parallax amount of the image selected by the optimal image selecting means is obtained using a parallax obtaining means. Then, images are corrected based on the shake amount and the parallax amount obtained in step 1510 and are combined and then, an image is output in step 1511. This completes a series of image capture operation. Hereinafter, a detailed description will be provided with reference to an example.

[0164]

(Example 5)

FIG. 16 illustrates an imaging optical system, a pixel shift means, and an imaging element according to Embodiment 5. As compared with Example 1 of FIG. 6, in a basic configuration of the present example, lenses 1601a, 1601b and an imaging element 1603 of an imaging optical system, similar to those of Example 1, are used. However, the present example is different in that two glass plates 1602a, 1602b are used as the pixel shift means.

[0165]

A method for pixel shift using glass plate is similar to the method indicated in Example 1. However, the present example makes it possible to perform pixel shift in the X direction and the Y direction in FIG. 16 by tilting the glass plates. A tilting means is not illustrated in FIG. 16. In this example, a pixel shift in the X direction is performed by tilting the glass plate 1602a and a pixel shift in the Y direction is performed by tilting the glass plate 1602b. For each of the glass plates 1602a and 1602b, BK7 similar to that in Example 1 is used.

[0166]

In this example, images are captured four times by performing pixel shift. FIG. 17 shows a sequence of performing pixel shift. In the pixel shift, a shift amount is set to be a half pixel pitch both in the horizontal and vertical direction of the imaging element, which is 1.2 μm. In an example of FIG. 17A, an image is captured without pixel shift (first image) and then, an image is captured by tilting the glass plate 1602a in the X direction by an amount that corresponds to 1/2 pitch (second image). Next, an image is captured by tilting the glass plate 1602b in the Y direction by an amount that corresponds to a 1/2 pitch while keeping the position of the glass plate

1602a the same (third image). Finally, an image is captured by tilting the glass plate 1602a in the X direction by an amount that corresponds to a -1/2 pitch while keeping the position of the glass plate 1602b the same (fourth image). By doing this, the imaged state in which invalid portions in each of the pixels are interpolated as in FIG. 17B can be obtained.

[0167]

In the present example, an image capture is performed for a scene in which movement of a subject is sufficiently small (for example, landscape and the like). Therefore, it is free from a subject shake and even when there is a shake, it may be assumed that the shake is resulted from a move of the entire image due to a photographer shake. A shake amount is obtained in a manner similar to that in Example 1.

[0168]

First, a result of image capture without using a shift amount determining means is shown in FIG. 18 using the flowchart of FIG. 2 in Embodiment 1. In FIG. 18, an intended shift amount of pixel shift (shift amount in FIG. 18), a shake amount obtained by each image capture (optical system without pixel shift in FIG. 18), and an image captured by an optical system with pixel shift (optical system with pixel shift in FIG. 18) are illustrated together.

[0169]

In FIG. 18, a shift amount of pixel shift is represented by a vector in solid lines and a shake amount obtained is represented by a vector in broken lines. Although each of the vectors appears only in an optical-to-electrical conversion portion at the upper left end, a shift due to a pixel shift and a shake during an image capture are supposed to be present equally for the same vector in all of the image capture regions. Hereinafter, a description

will be given in accordance with a flow in the image capture using FIG. 18.

[0170]

First, image capture was performed to obtain four images in the order of pixel shift as shown in FIG. 17. Next, an image captured by an optical system that does not perform pixel shift was compared to obtain a shake amount. The obtained shake amount is as shown in FIG. 18.

[0171]

No shake was obtained in the first image captured but in the second image captured, with respect to the optical system that does not perform pixel shift, there was a shake in the entire image at a position in FIG. 17 where the third image capture was intended. In such a case, with respect to the optical system that performs pixel shift, an image capture was performed at the position in FIG. 17 where the fourth image capture was intended (see third column in a second image's row in FIG. 18).

[0172]

For the third image captured, there was a shake in the entire image at the optical-to-electrical conversion portion with respect to the optical system that does not perform pixel shift. In such a case, with respect to the optical system that performs pixel shift, an image capture was performed at the position in FIG. 17 where the third image capture was intended (see third column in a third image's row in FIG. 18).

[0173]

For the fourth image captured, there was a shake in the entire image at the optical-to-electrical conversion portion with respect to the optical system that does not perform pixel shift. In such a case, with respect to the optical system that performs pixel shift, an image capture was performed at the position in FIG. 17 where the fourth image capture was

intended (see third column in a fourth image's row in FIG. 18).

[0174]

Next, based on the obtained shake amount, an image that is optimal for combining was selected using an optimal image selecting means. Information on the image obtained by image capture are only the first, third, and fourth image capture intended in FIG. 17 as described above. Thus, the optimal image selecting means selected images with shaded area from among the images of the optical system that performed pixel shift in FIG. 18. The selected images were then corrected based on the shake amount obtained to combine images. The combined image was output in the end, which completes a series of image captures.

[0175]

By performing the pixel shift and subsequent combining of images using the optimal image selecting means in this way, the image improves a resolution reliably. However, because the combining of images was performed while information on the second image capture intended in FIG. 17 was missing, it failed to achieve a resolution as substantially expected.

[0176]

In this regard, an image capture was performed in the present example using a flowchart as shown in FIG. 15. The result of image capture is illustrated in FIG. 19. Hereinafter, a description will be given in accordance with a flow in the image capture using FIG. 19.

[0177]

First, the first image was captured. When an attempt was made to obtain a shake amount using the shake amount obtaining means 108, no shake was obtained for the first image capture. Based on the obtained shake amount, an image from the first image capture with a shade region in

FIG. 19 was selected by the optimal image selecting means 109. Next, a shift amount for the second image capture was determined using the shift amount determining means to be set at the position in FIG. 17 where the second image capture was performed as intended.

[0178]

Next, the second image was captured. When an attempt was made to obtain a shake amount using the shake amount obtaining means 108, a shake was obtained at the position in FIG. 17 where the third image capture was intended in the optical system that does not perform pixel shift in the second image captured. In such a case, with respect to the optical system that performs pixel shift, an image capture was performed at the position in FIG. 17 where the fourth image capture was intended (see the third column in a second image's row in FIG. 19). Based on the obtained shake amount, an image captured by the optical system that does not perform pixel shift in the second image captured and an image captured by the optical system that performs pixel shift that are illustrated in FIG. 19 with shaded region were both selected using the optimal image selecting means 109.

[0179]

Next, using a shift amount determining means, a shift amount for pixel shift in the third image was determined to be set at a position in FIG. 17 for the second image capture where an image capture were not possible.

[0180]

Next, the third image was captured. When an attempt was made to obtain a shake amount using the shake amount obtaining means, a shake was obtained at the optical-to-electrical conversion portion with respect to the optical system that does not perform pixel shift. In such a case, with respect to the optical system that performs pixel shift, an image capture was

performed at the position in FIG. 17 where the second image capture was intended (see the third column in a third image's row in FIG. 19). Based on the obtained shake amount, an image that is illustrated in FIG. 19 with shaded region was selected using the optimal image selecting means.

[0181]

By the end of the third image capture, information on four images that are intended to be captured were provided, so that the image capture was terminated by the third image capture. Next, based on the shake amount and parallax amount obtained in each image capture, the image selected by the optimal image selecting means was corrected to perform combining of images by the image combining means, thereby an image with improved resolution was obtained.

[0182]

By using the shift amount determining means, the shift amount is varied each time the pixel shift is performed to capture an image even when the image capture is not performed as intended at the beginning, whereby an image with improved resolution is obtained.

[0183]

In addition, in this example, each of the image capture is performed followed by determining of a shift amount for a pixel shift using a shift amount determining means to perform the next image capture. However, it may also be possible to perform image capture for a plurality of images before determining a shift amount for a pixel shift in the subsequent image capture using a shift amount determining means. In such a case, shift amounts for the subsequent image capture can be determined using information on images captured in a series, which saves time for image capture.

[0184]

Furthermore, a pixel shift in the X direction is performed using a glass plate 1602a and a pixel shift in the Y direction is performed using a glass plate 1602b in the present example. However, it is possible that the respective pixel shift may be performed in the other direction.

[0185]

Furthermore, in the present example, although a pixel shift in the X and Y directions are performed using two glass plates, the pixel shift may be performed such that one glass plate is used and is actuated separately in the X and Y directions using the tilting means.

[0186]

Although, in this example, a method of tilting the glass plate is used as the pixel shift means, the method is not limited thereto. For example, an actuator employing a piezoelectric element, an electromagnetic actuator, or the like may be used to mechanically move the imaging element or the lens in a predetermined amount.

[0187]

In this example, a glass plate is not provided in the optical system that does not perform pixel shift. However, a pixel shift is not performed by the optical system provided with the glass plate which is not intended to be tilted. With this configuration, more flexibility will be available in a choice between with and without the pixel shift compared to the configuration in which the pixel shift means is not provided from the first place.

[0188]

This configuration is the same for another method of performing pixel shift as mentioned above. For example, when an actuator employing

a piezoelectric element is used as a pixel shift means, a pixel shift is intended not to be performed by not providing an actuator from the first place. However, it is also possible that the pixel shift is intended not to be performed by providing an actuator which is not intentionally moved. As in the case of the above-mentioned parallel plane, this case provides more flexibility in a choice between with and without the pixel shift compared to the configuration in which the pixel shift means is not provided from the first place.

[0189]

Although, in this example, one imaging element is divided into two regions, two different imaging elements may be employed for the respective optical systems in one-to-one correspondence. Any form of imaging element may be used as long as a plurality of imaging regions corresponds to respective optical systems in one-to-one correspondence.

[0190]

In the present example, an image capture is performed in a situation where it is only a photographer shake that can be assumed of a shake, and where there is a shake evenly in the entire image. However, the present example also includes a case where there is a subject shake and the shake amount of the entire image is not even. For example, when an image selected by the optimal image selecting means 109 is different for different block or different subject, a shift amount determined by the shift amount selecting means can be selected so that some of the images are optimized.

[0191]

For example, a shift amount can be selected so as to make a specific subject (human) have a high resolution. In such a case, it is possible that a portion of the image excluding some of the images being selected is not

improved of a resolution by pixel shift, and only the first image captured is selected.

[0192]

FIG. 20 shows a result of image capture according to another example where an image is captured using a flowchart illustrated in FIG. 15. An example shown in FIG. 20 is a case where four times of image capture was performed in an order illustrated in FIG. 17 and an attempt was made to improve a resolution. There was no shake obtained until the third image capture and the image capture was performed as intended, but there was a shake in the fourth image capture as shown in FIG. 20.

[0193]

In this case, the only information obtained up to the fourth image capture was on the first, second, and third image captures as intended. Accordingly, combining of these images is performed while the fourth image intended to be captured is missing, so that the improvement of a resolution is not achieved as intended.

[0194]

Consequently, in an example as shown in FIG. 20, image capture was performed until the fourth image intended to be captured in FIG. 17 can be obtained. A shake was obtained as shown in FIG. 20 when the fifth image was captured. On the fifth image capture, an image of an optical system without pixel shift corresponds to the fourth image intended to be captured in FIG. 17. Thus, the optimal image selecting means 109 selected an image captured without pixel shift from the fifth image capture, thereby completing the image capture.

[0195]

Accordingly, when an intended image cannot be obtained in

improving of a resolution using pixel shift technique, the image capture may be performed repeatedly until the intended image is obtained. Also, this can be applied not only to a case described above with reference to FIG. 20 where the last image capture alone is an unintended image but also a case where the image captures along the way was not performed as intended.

[Industrial Applicability]

[0196]

As described above, according to the present invention, even if there is a photographer shake or a subject shake when pixel shift is performed, it is possible to reduce a reduction in effect of pixel shift, and obtain a high-resolution image. Therefore, the present invention is useful for, for example, an imaging apparatus used in a digital still camera, a mobile telephone, or the like.

[Brief Description of the Drawings]

[0197]

[Fig. 1] FIG. 1 is a block diagram illustrating a configuration of an imaging apparatus according to Embodiment 1 of the present invention.

[Fig. 2] FIG. 2 is a flowchart illustrating a whole operation of the imaging apparatus of Embodiment 1 of the present invention.

[Fig. 3] FIG. 3 is a diagram illustrating a positional relationship between a comparative reference region and an evaluation region according to an embodiment of the present invention.

[Fig. 4] FIG. 4 is a conceptual diagram of a method of selecting an optimal image according to an embodiment of the present invention.

[Fig. 5] FIG. 5 is a conceptual diagram of a method of correcting a shake amount according to an embodiment of the present invention.

[Fig. 6] FIG. 6 is a diagram illustrating a configuration of an

imaging optical system, a pixel shift means, and an imaging element according to Example 1 of the present invention.

[Fig. 7] FIG. 7 is a diagram illustrating an image which is stored into a memory in Example 1 of the present invention.

[Fig. 8] FIG 8 is a conceptual diagram showing an example of a photographer shake.

[Fig. 9] FIG. 9 is a diagram illustrating an image which is stored into an memory in Example 2 of the present invention.

[Fig. 10] FIG. 10 is a diagram illustrating a captured image and subject groups discriminated by a subject discriminating means in Example 3 of the present invention.

[Fig. 11] FIG. 11 is a diagram illustrating a configuration of an imaging optical system, a pixel shift means, and an imaging element according to Embodiment 2 of the present invention.

[Fig. 12] FIG. 12 is a top view of a piezoelectric small movement mechanism according to Example 4 of the present invention.

[Fig. 13] FIG. 13 is a diagram for explaining a parallax.

[Fig. 14] FIG. 14 is a diagram illustrating an exemplary arrangement of optical systems according to an embodiment of the present invention.

[Fig. 15] FIG. 15 is a flowchart illustrating a whole operation of an imaging apparatus of Embodiment 3 of the present invention.

[Fig. 16] FIG. 16 is a diagram illustrating a configuration of an imaging optical system, a pixel shift means, and an imaging element according to Example 5 of the present invention.

[Fig. 17] FIG. 17 is a diagram illustrating a sequence of image capture according to Example 5 of the present invention.

[Fig. 18] FIG. 18 is a diagram illustrating a result of image capture performed using a flowchart of FIG. 2 in Embodiment 5 of the present invention.

[Fig. 19] FIG. 19 is a diagram illustrating a result of image capture performed using a flowchart of FIG. 11 in Embodiment 5 of the present invention.

[Fig. 20] FIG. 20 is a diagram illustrating a result of image capture performed using a flowchart of FIG. 11 in Embodiment 5 of the present invention.

[Fig. 21] FIG. 21 is a conceptual diagram illustrating an example of improving a resolution using a conventional pixel shift technique.

[Fig. 22] FIG. 22 is a diagram for explaining a problem in the conventional pixel shift technique.

[Fig. 23] FIG. 23 is a diagram for explaining a problem in the conventional pixel shift technique.

[Description of the Reference Numerals]

[0198]

102	pixel shift means
104	imaging optical system without pixel shift
105	imaging optical system with pixel shift
106	imaging element
107	memory
108	shake amount obtaining means
109	optimal image selecting means
110	image combining means
1101a, 1101b, 1101c, 1101d	lenses
1102a, 1102b, 1102c, 1102d	color filters

1104 piezoelectric small movement mechanism

[Document Name] ABSTRACT

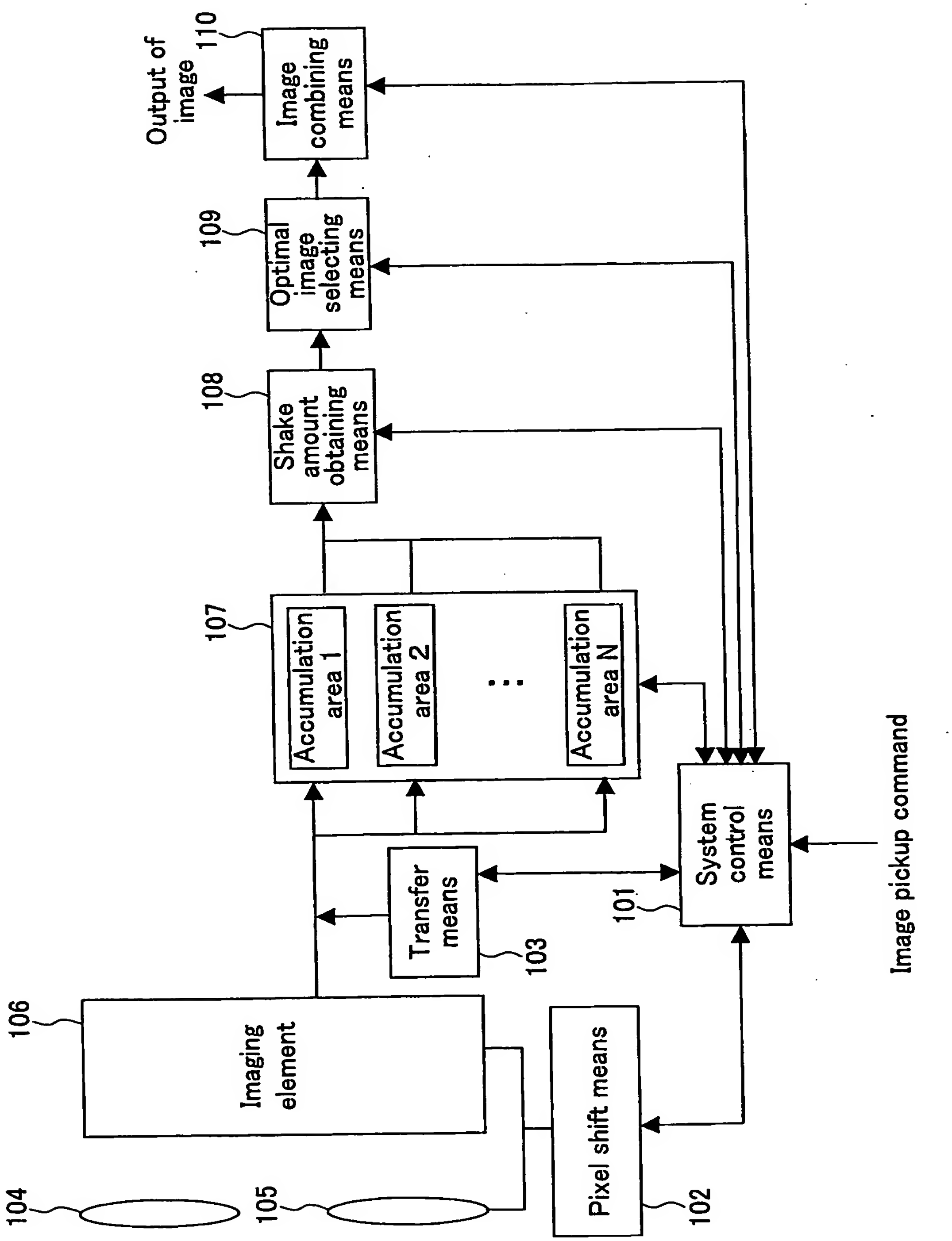
[Abstract]

[Objective] To provide an imaging apparatus that performs a pixel shift and can prevent a reduction in the effect of the pixel shift even if there is a photographer shake or a subject shake.

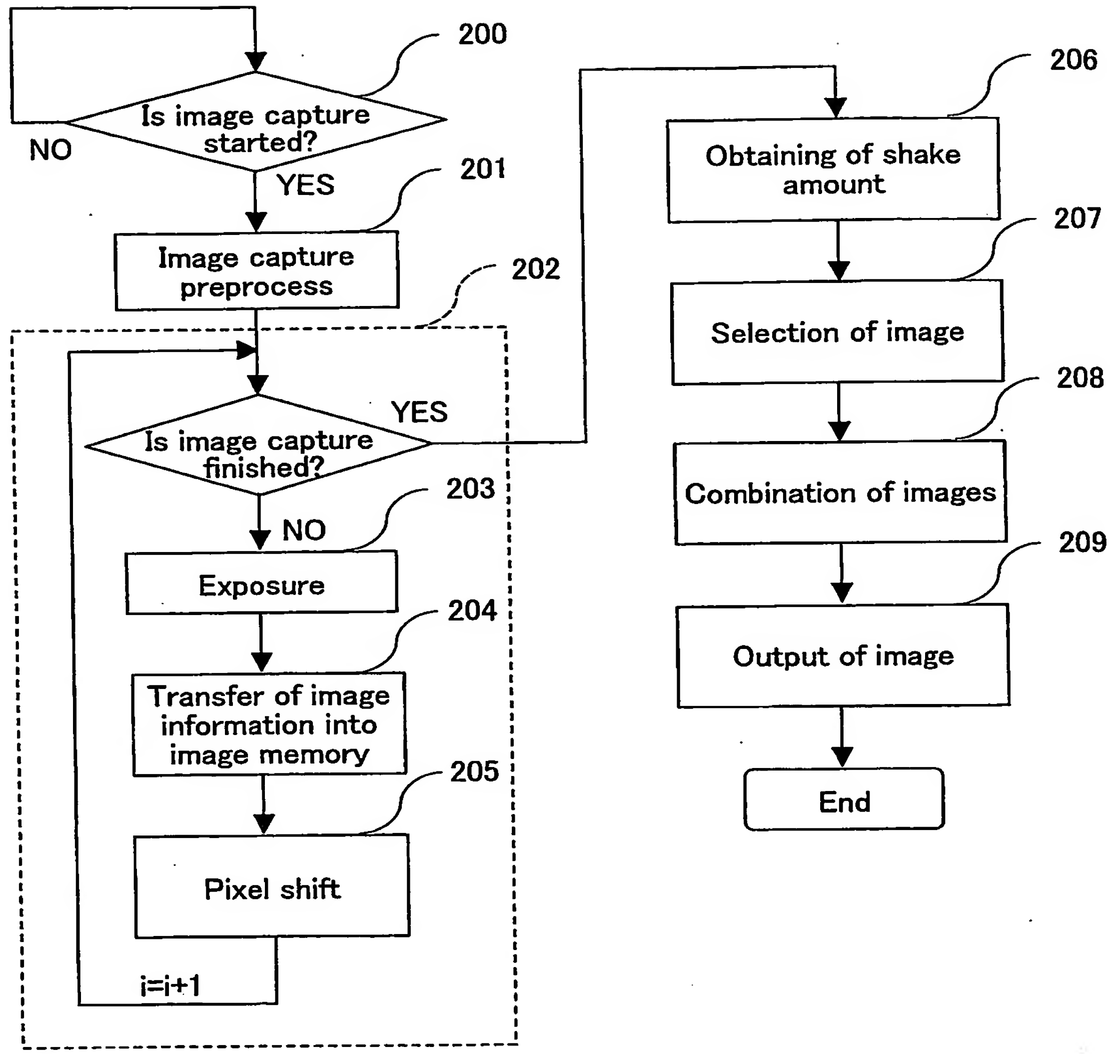
[Means for Solving the Problem] A pixel shift means 102 does not perform a pixel shift on images formed by one of the optical systems 104, 105, but performs a pixel shift on images formed by the other optical system. A shake amount obtaining means 108 obtains the shake amount of an image by comparing a plurality of pieces of image information captured in time series by the optical system without performing the pixel shift and stored in a memory 107. An optimal image selecting means 109 selects images used for image combination based on the shake amount obtained by the shake amount obtaining means 108. An image combining means 110 corrects the selected images based on the shake amount obtained by the shake amount obtaining means 108, and then combines the images.

[Selected Figure] FIG. 1

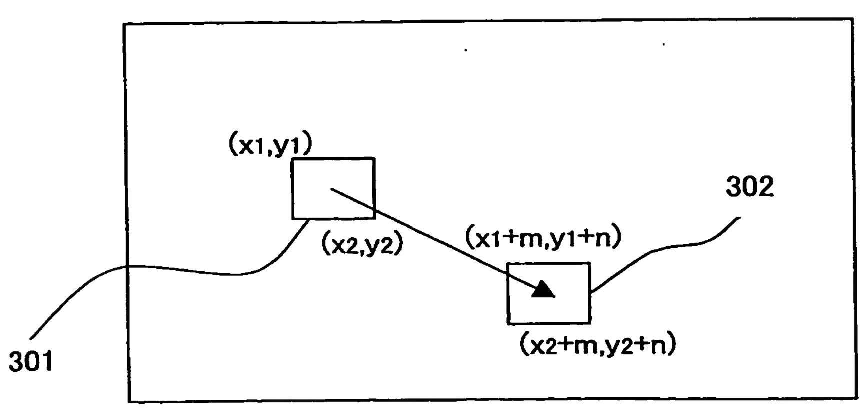
[Document Name] Drawings
[FIG. 1]



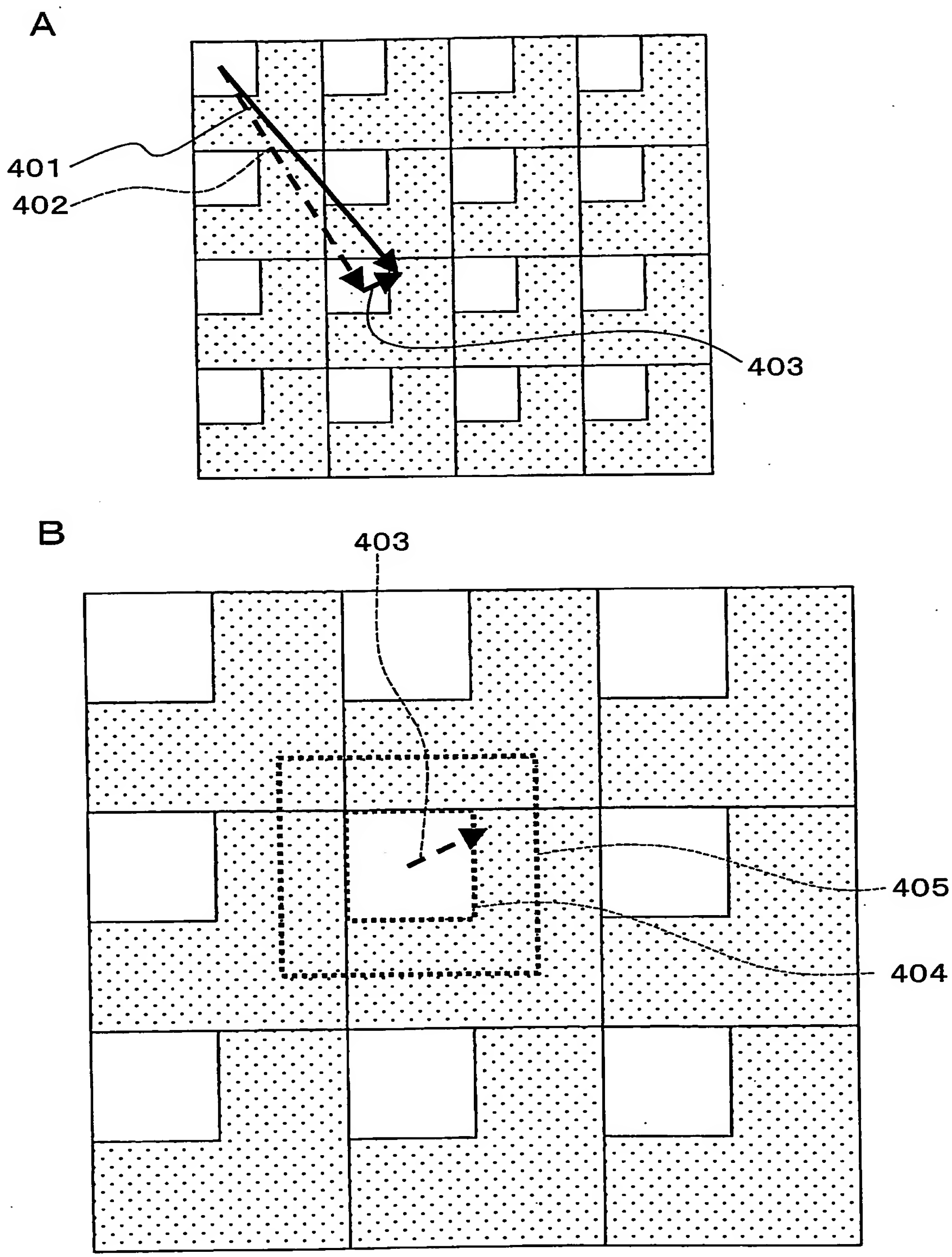
[FIG. 2]


200
Is image capture started?
NO
YES
201
Image capture preprocess
202
Is image capture finished?
YES
NO
203
Exposure
204
Transfer of image information into image memory
205
Pixel shift
i=i+1
206
Obtaining of shake amount
207
Selection of image
208
Combination of images
209
Output of image
End

[FIG. 3]


(x1,y1)
(x2,y2)
(x1+m,y1+n)
(x2+m,y2+n)
301
302

[FIG. 4]



[FIG. 5]

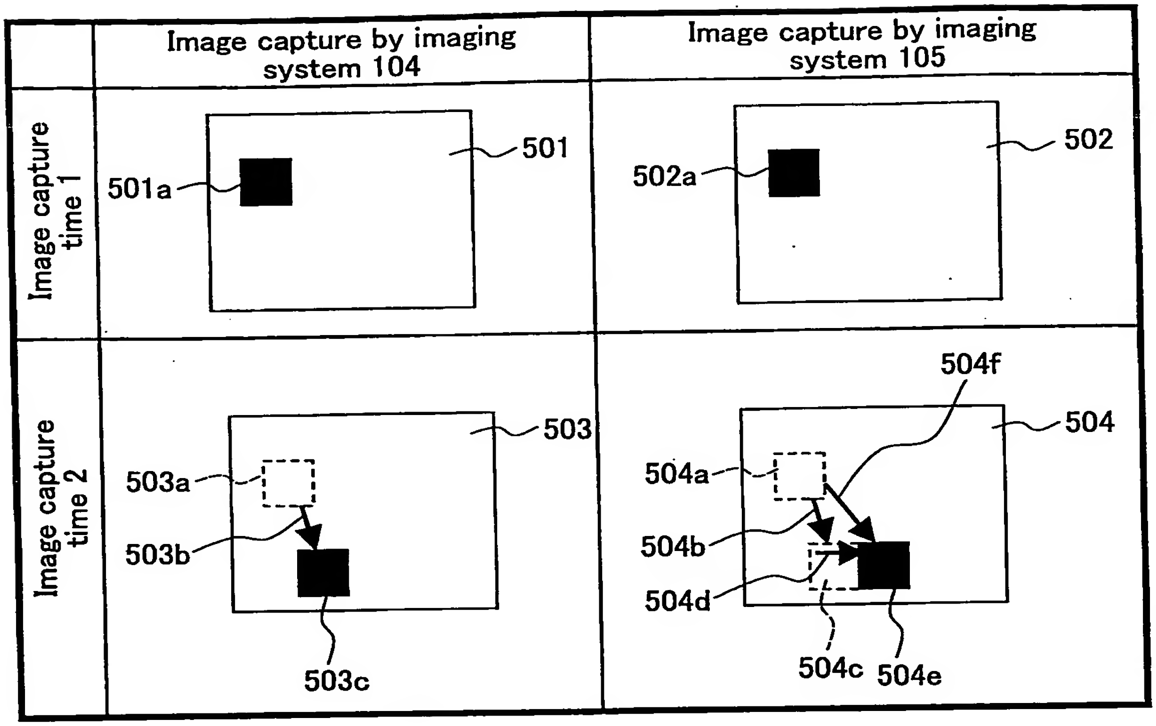
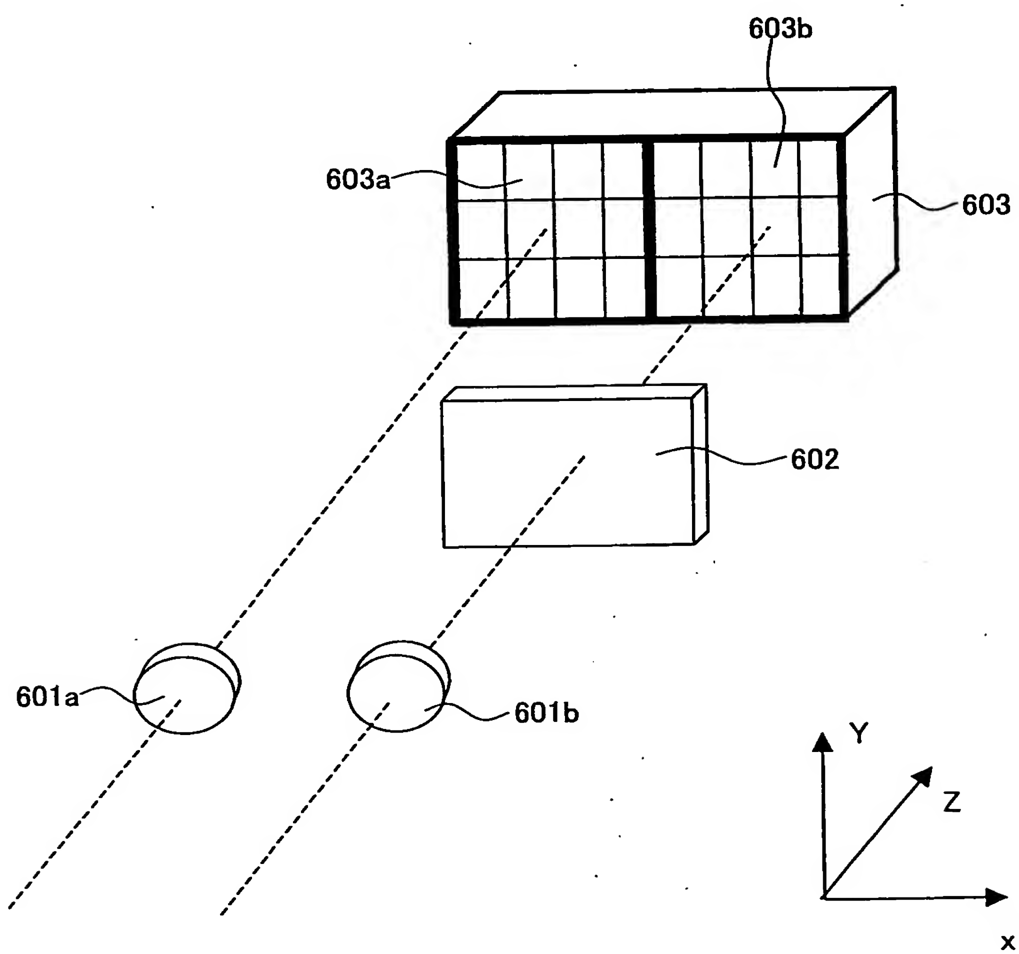


Image capture by imaging system 104
Image capture by imaging system 105
Image capture time 1
Image capture time 2
501
501a
502
502a
503
503a
503b
503c
504
504a
504b
504c
504d
504e
504f

[FIG. 6]


603b
603a
603
602
601a
601b
Y
Z
x

[FIG. 7]

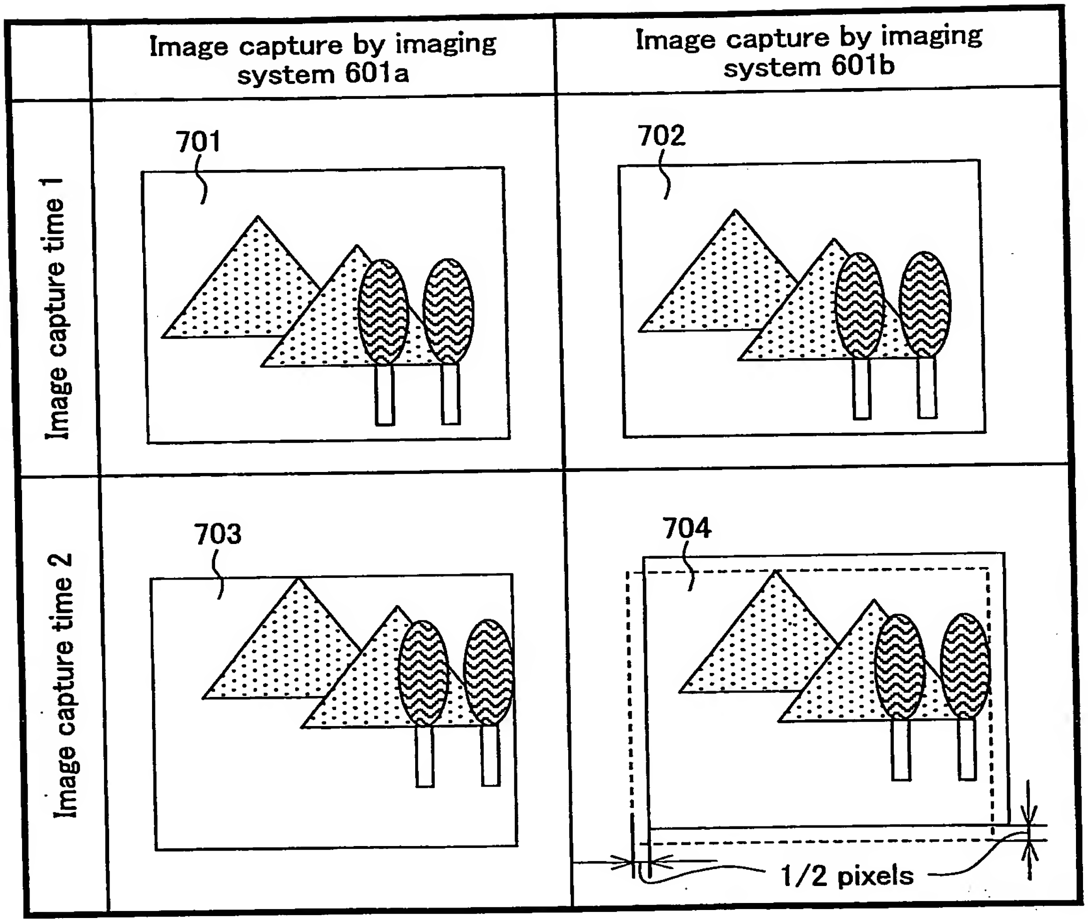
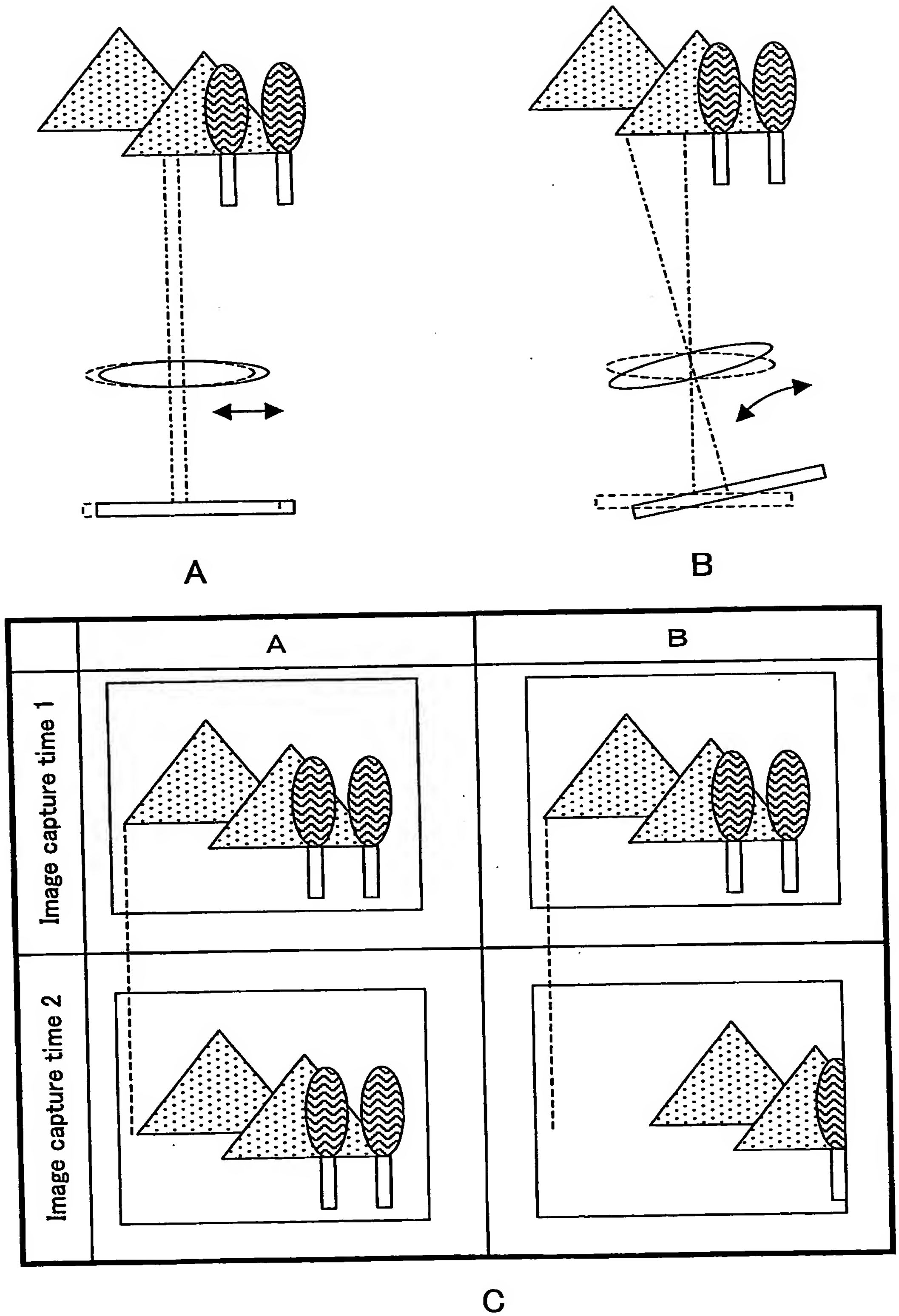


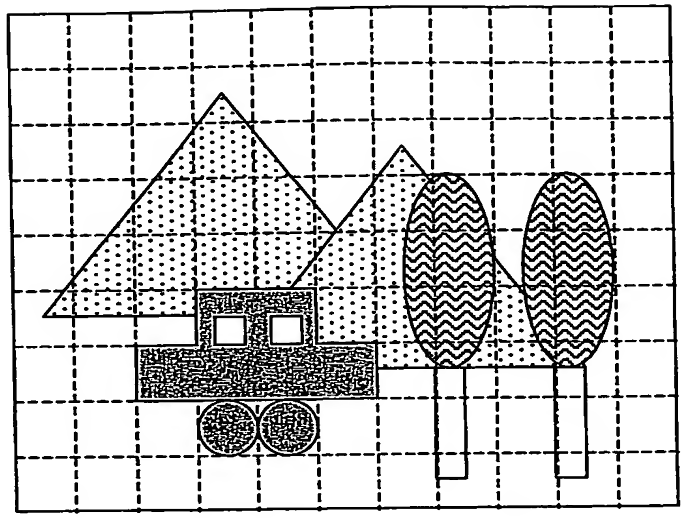
Image capture by imaging system 601a
Image capture by imaging system 601b
Image capture time 1
Image capture time 2
701
702
703
704
1/2 pixels

[FIG. 8]

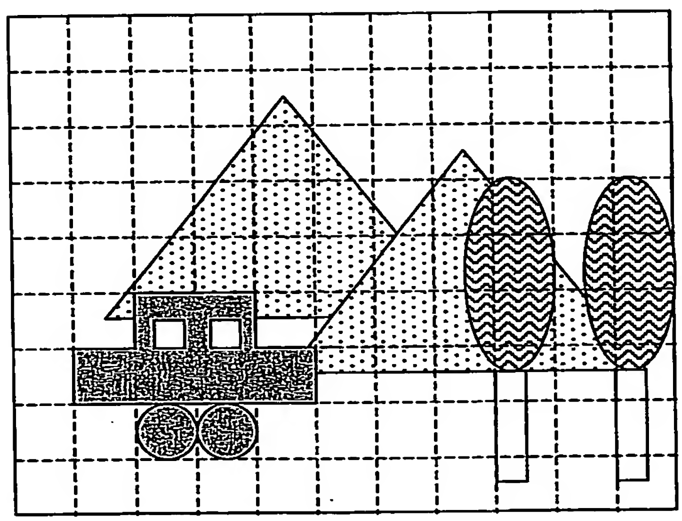


[FIG. 9]

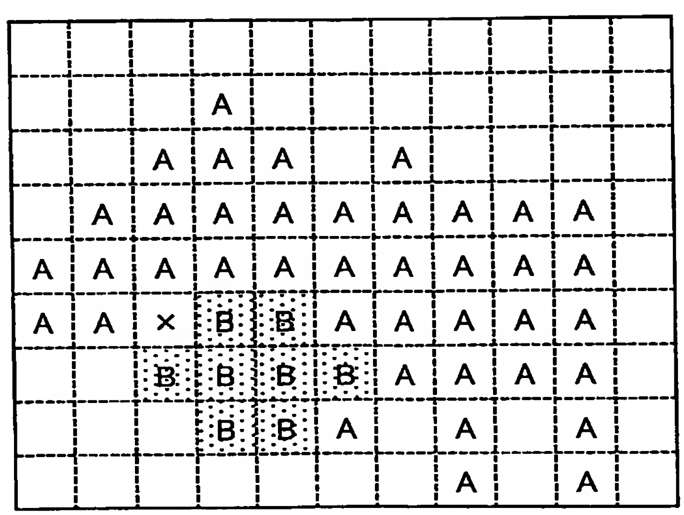
A



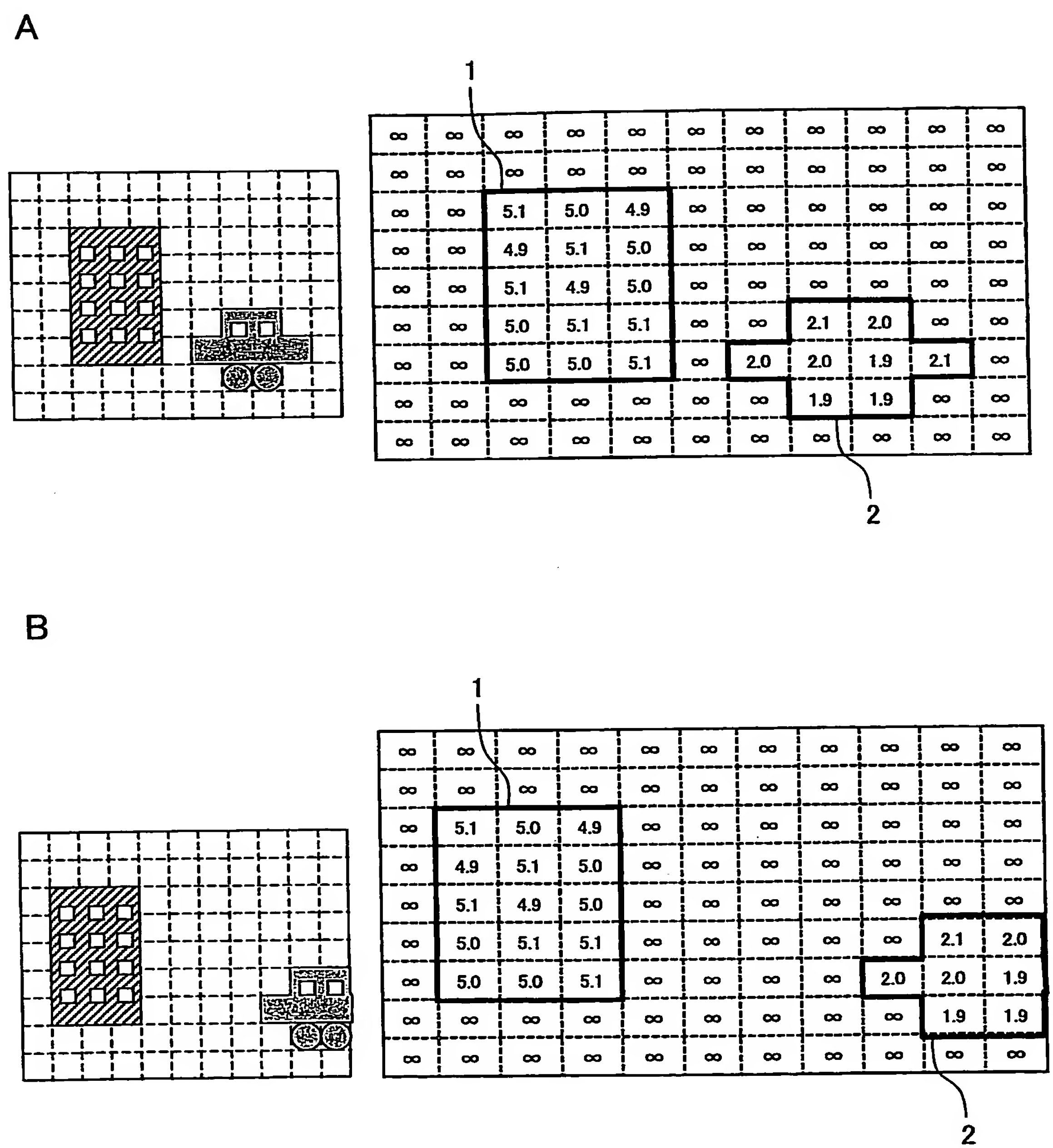
B



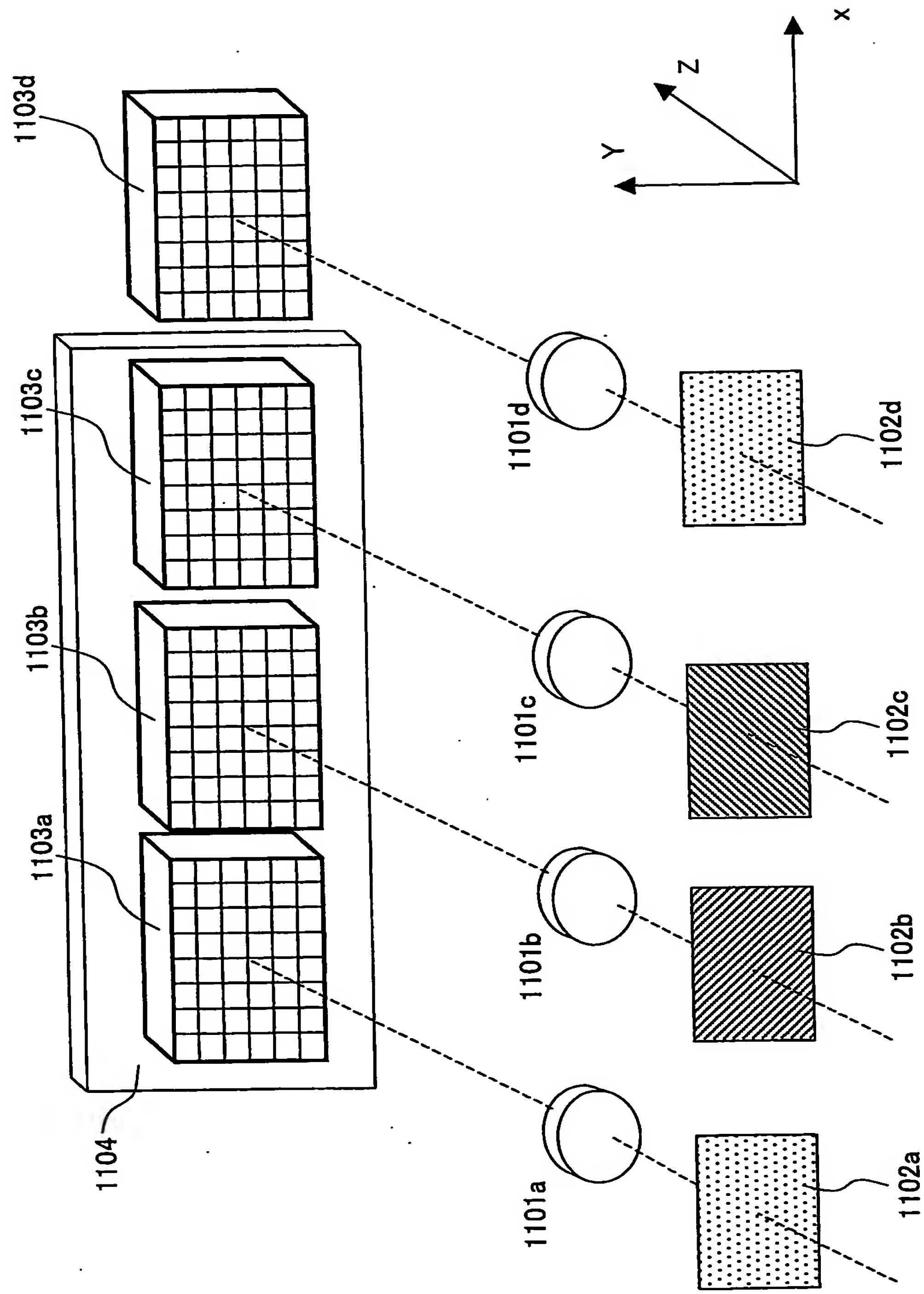
C



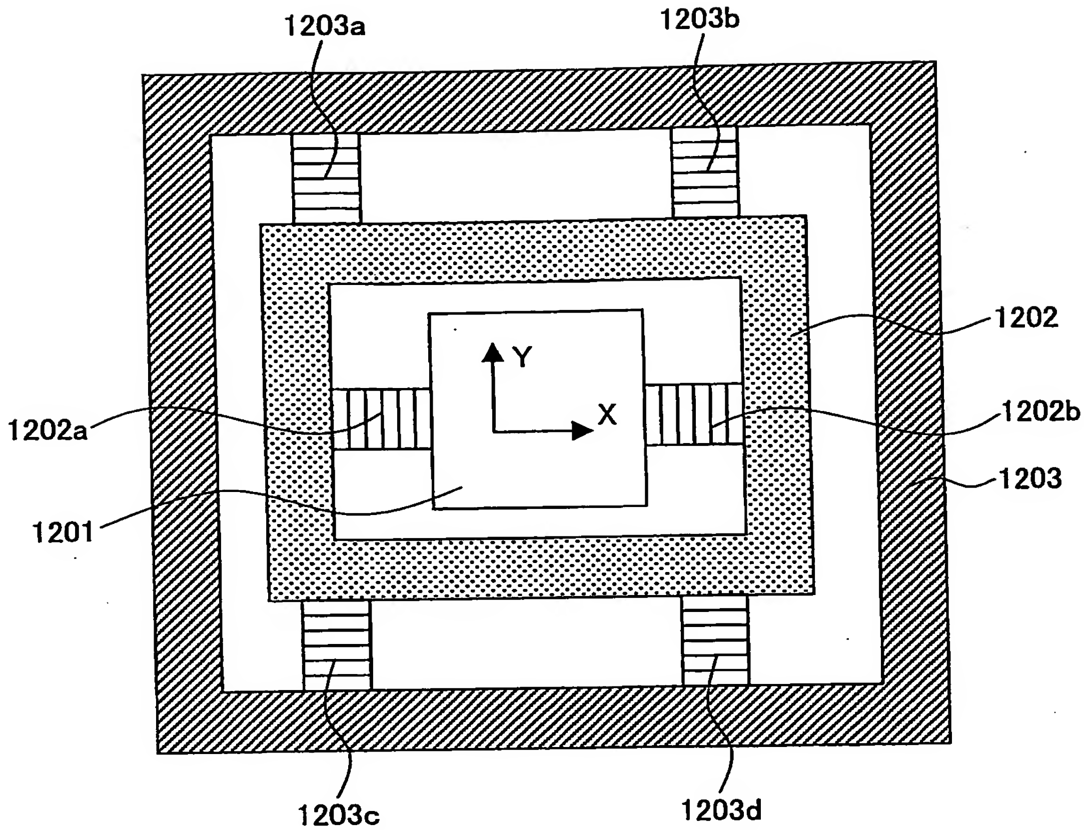
[FIG. 10]


A
1
∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞
∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞
∞ ∞ 5.1 5.0 4.9 ∞ ∞ ∞ ∞ ∞ ∞
∞ ∞ 4.9 5.1 5.0 ∞ ∞ ∞ ∞ ∞ ∞
∞ ∞ 5.1 4.9 5.0 ∞ ∞ ∞ ∞ ∞ ∞
∞ ∞ 5.0 5.1 5.1 ∞ ∞ 2.1 2.0 ∞ ∞
∞ ∞ 5.0 5.0 5.1 ∞ 2.0 2.0 1.9 2.1 ∞
∞ ∞ ∞ ∞ ∞ ∞ ∞ 1.9 1.9 ∞ ∞
∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞
2
B
1
∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞
∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞
∞ 5.1 5.0 4.9 ∞ ∞ ∞ ∞ ∞ ∞ ∞
∞ 4.9 5.1 5.0 ∞ ∞ ∞ ∞ ∞ ∞ ∞
∞ 5.1 4.9 5.0 ∞ ∞ ∞ ∞ ∞ ∞ ∞
∞ 5.0 5.1 5.1 ∞ ∞ ∞ ∞ ∞ 2.1 2.0
∞ 5.0 5.0 5.1 ∞ ∞ ∞ ∞ 2.0 2.0 1.9
∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ 1.9 1.9
∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞
2

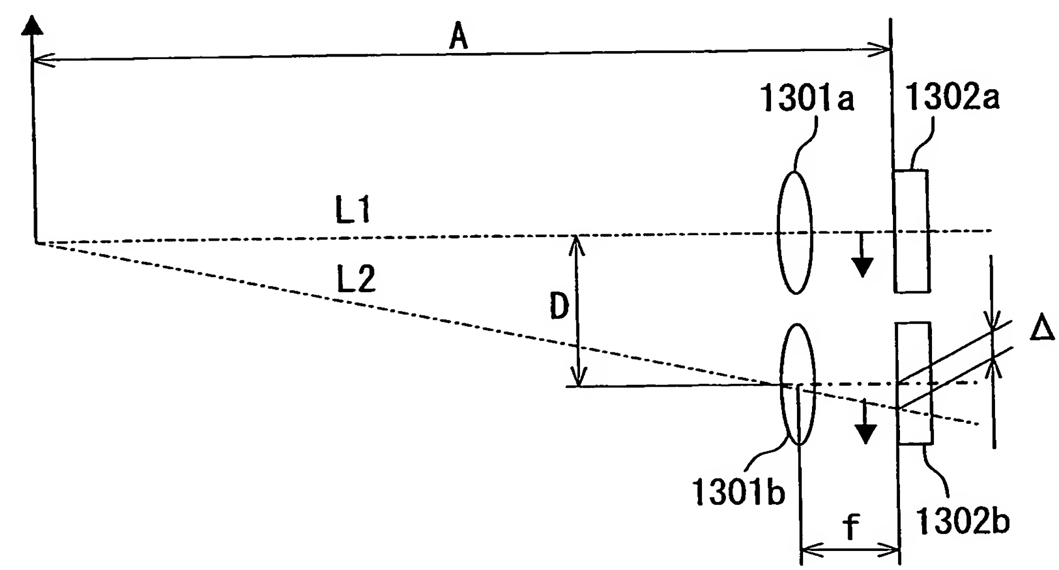
[FIG. 11]


1103d
1103c
1103b
1103a
1104
1101d
1101c
1101b
1101a
1102d
1102c
1102b
1102a
X
Y
Z

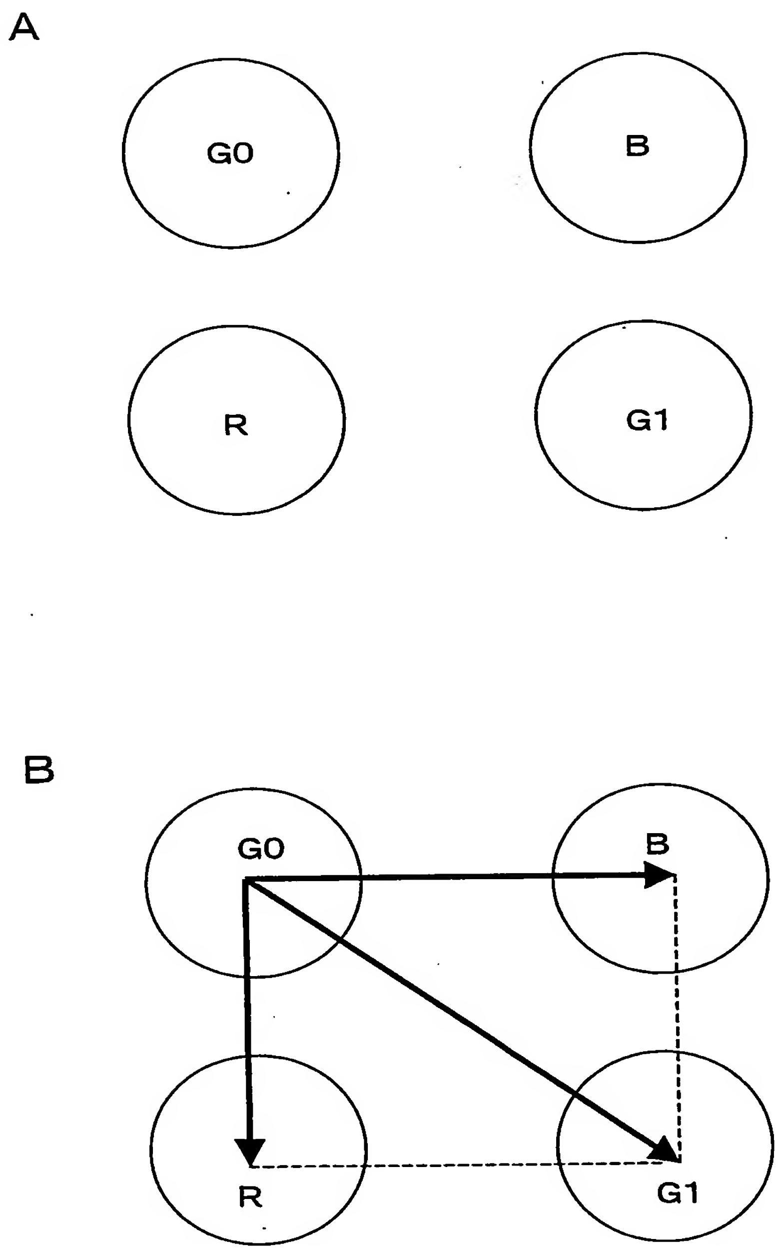
[FIG. 12]


1203a
1203b
1202
1202a
1202b
1203
1201
Y
X
1203c
1203d

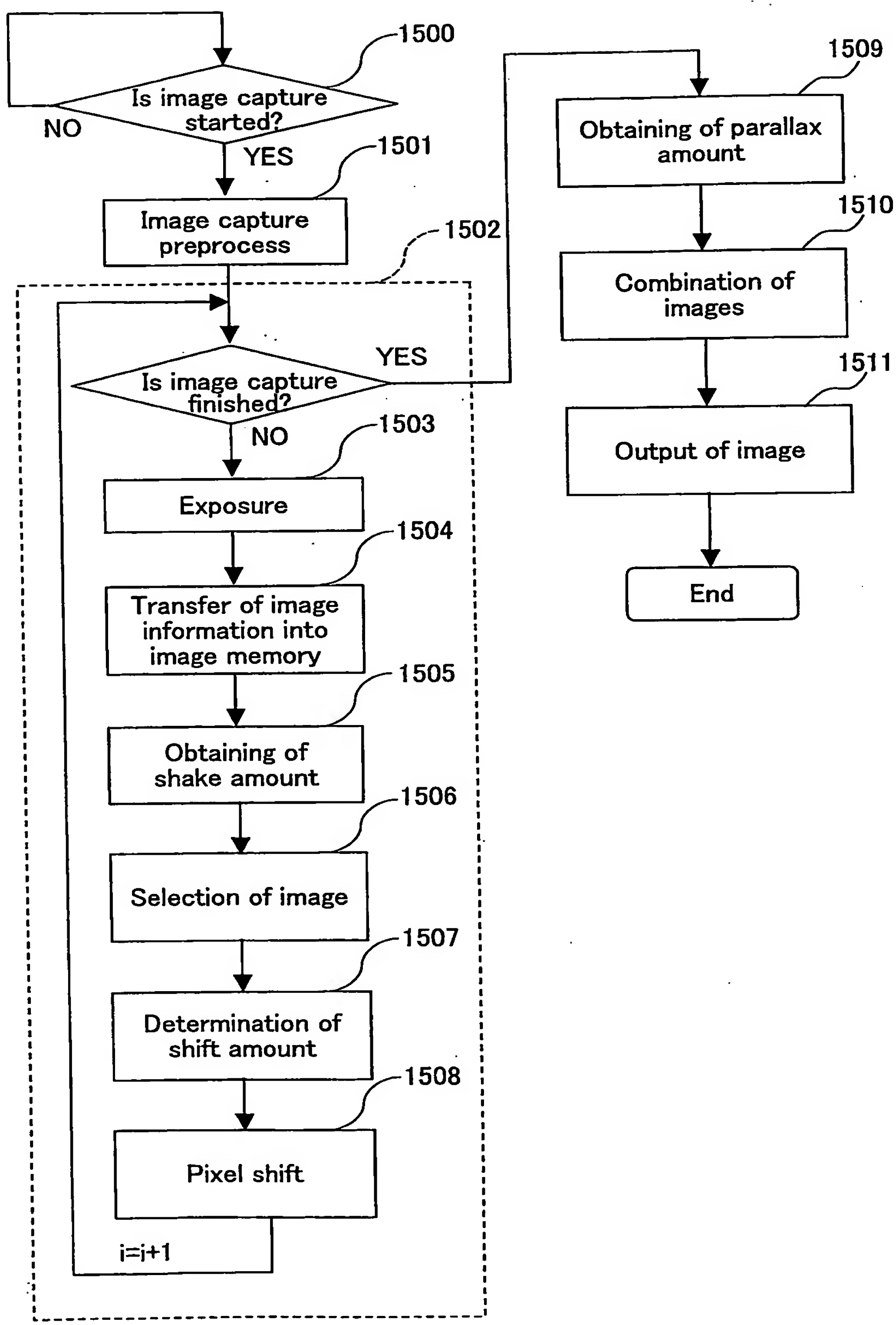
[FIG. 13]


A
1301a
1302a
L1
L2
D
Δ
1301b
f
1302b

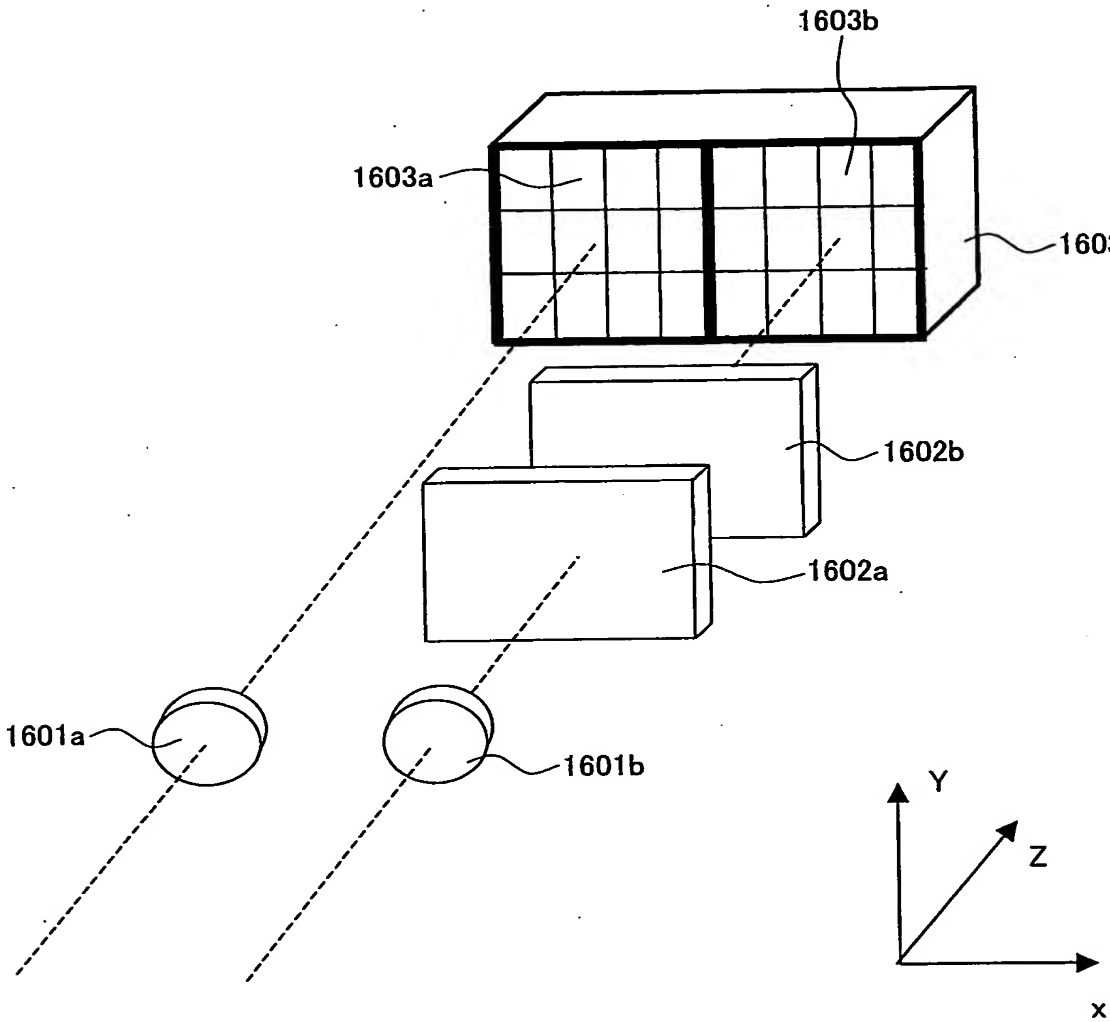
[FIG. 14]



[FIG. 15]

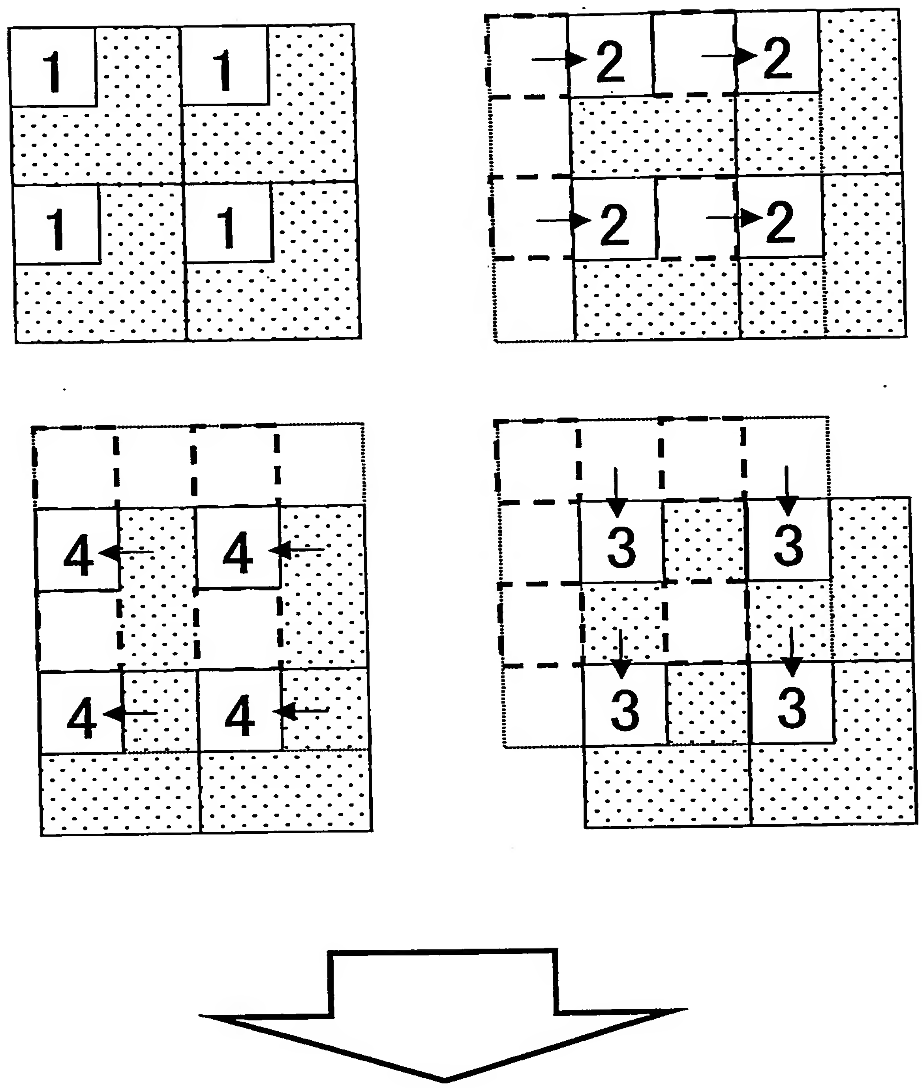

1500
Is image capture started?
NO
YES
1501
Image capture preprocess
1502
YES
Is image capture finished?
NO
1503
Exposure
1504
Transfer of image information into image memory
1505
Obtaining of shake amount
1506
Selection of image
1507
Determination of shift amount
1508
Pixel shift
i=i+1
1509
Obtaining of parallax amount
1510
Combination of images
1511
Output of image
End

[FIG. 16]



[FIG. 17]

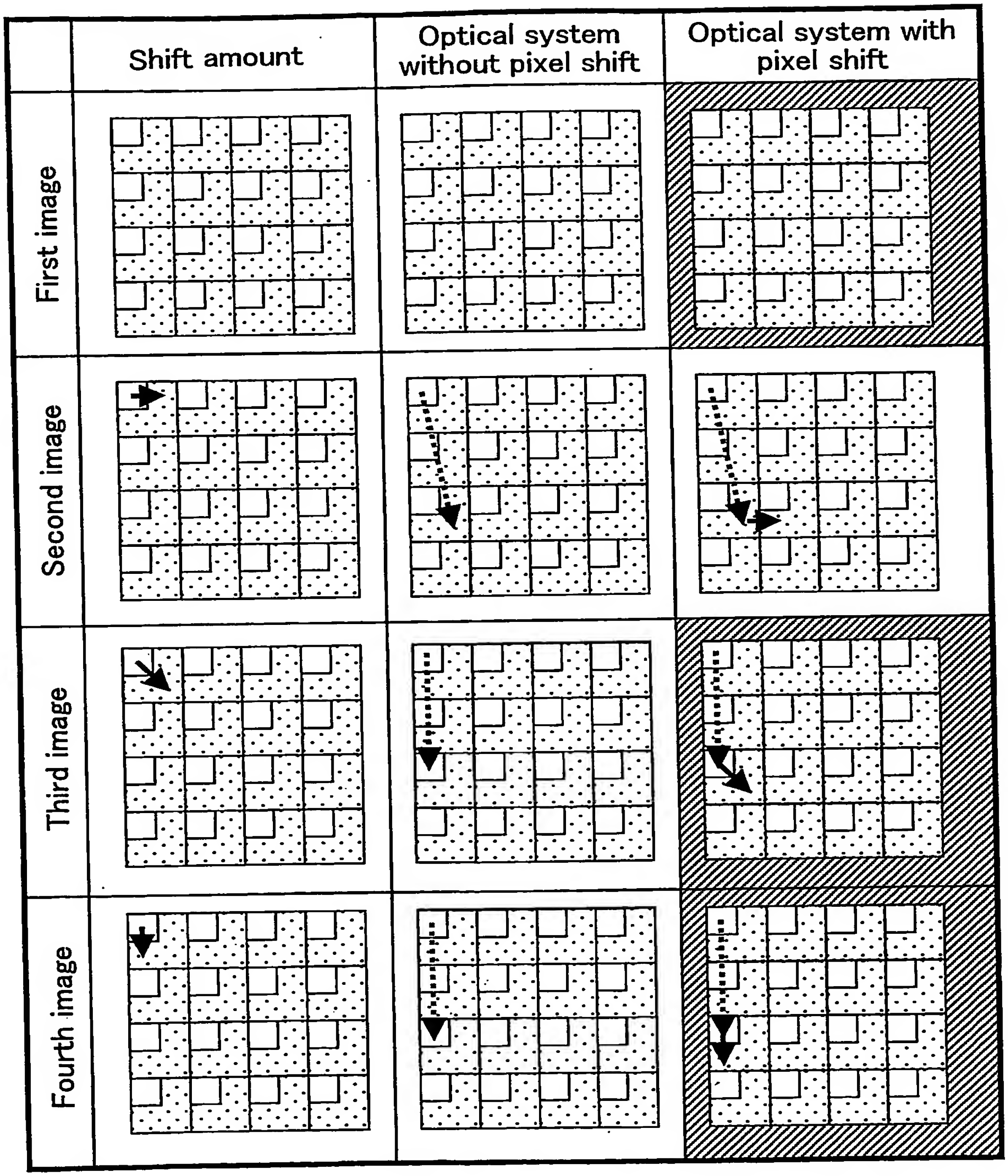
A



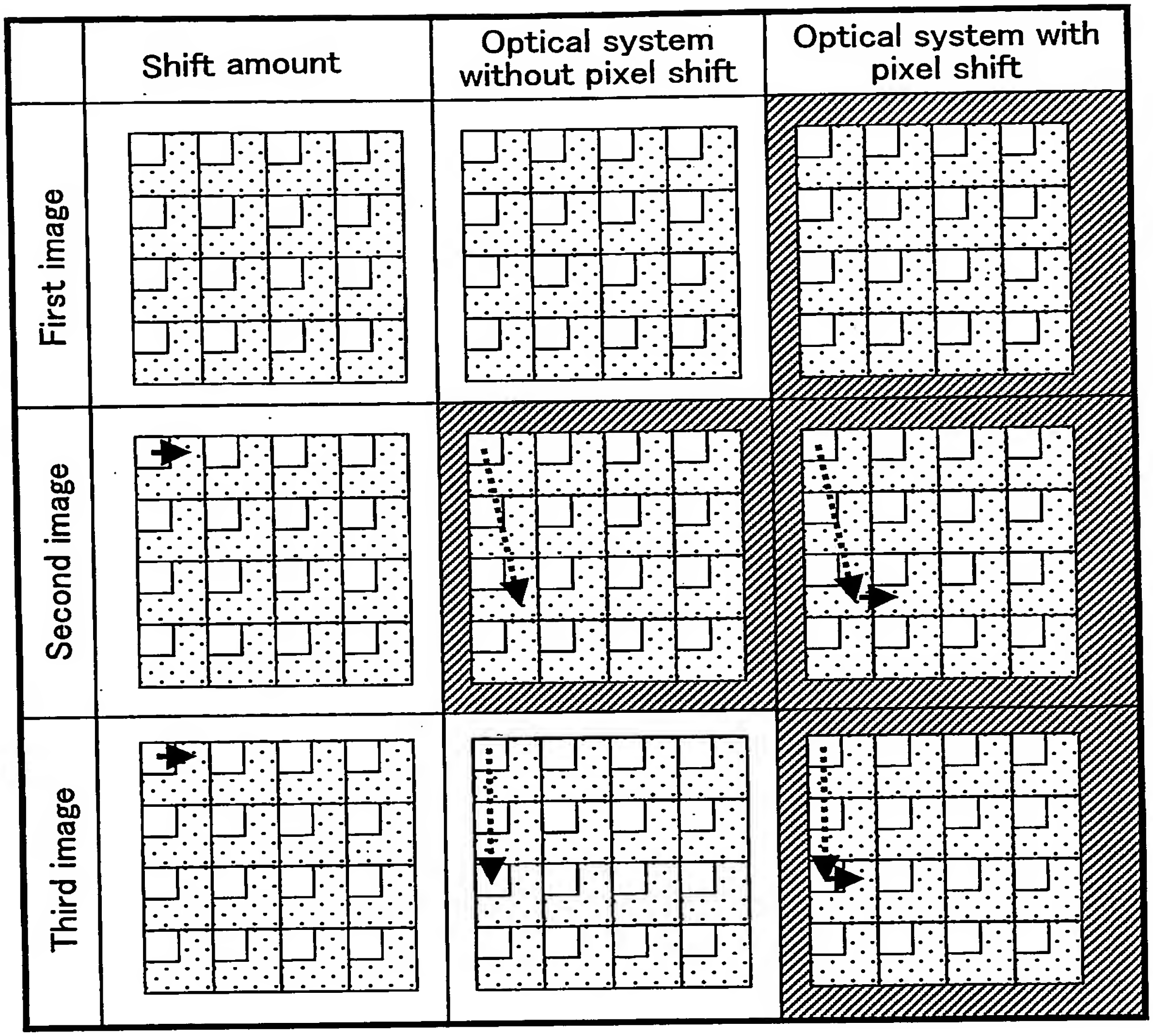
B

1	2	1	2
4	3	4	3
1	2	1	2
4	3	4	3

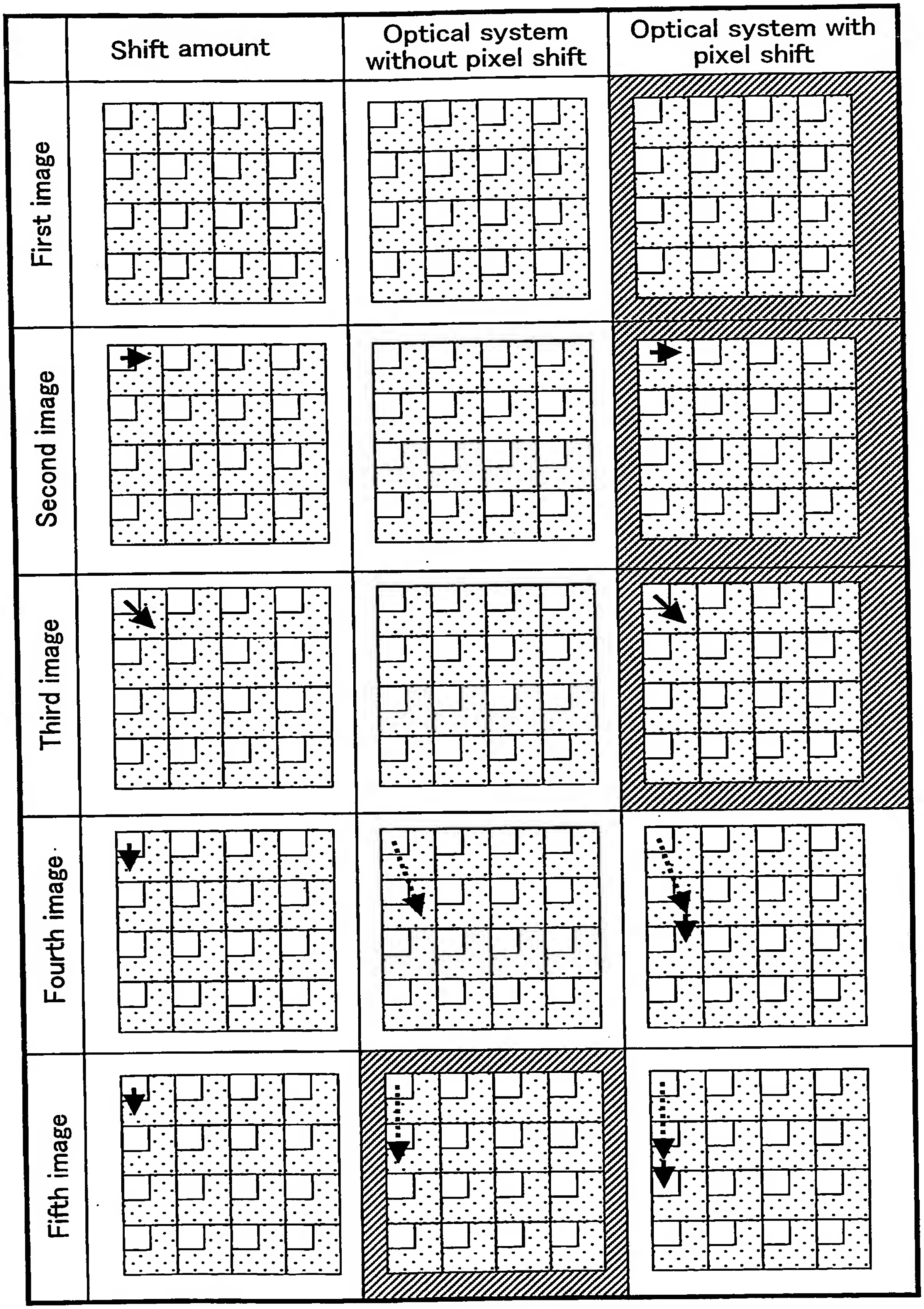
[FIG. 18]


Shift amount
Optical system without pixel shift
Optical system with pixel shift
First image
Second image
Third image
Fourth image

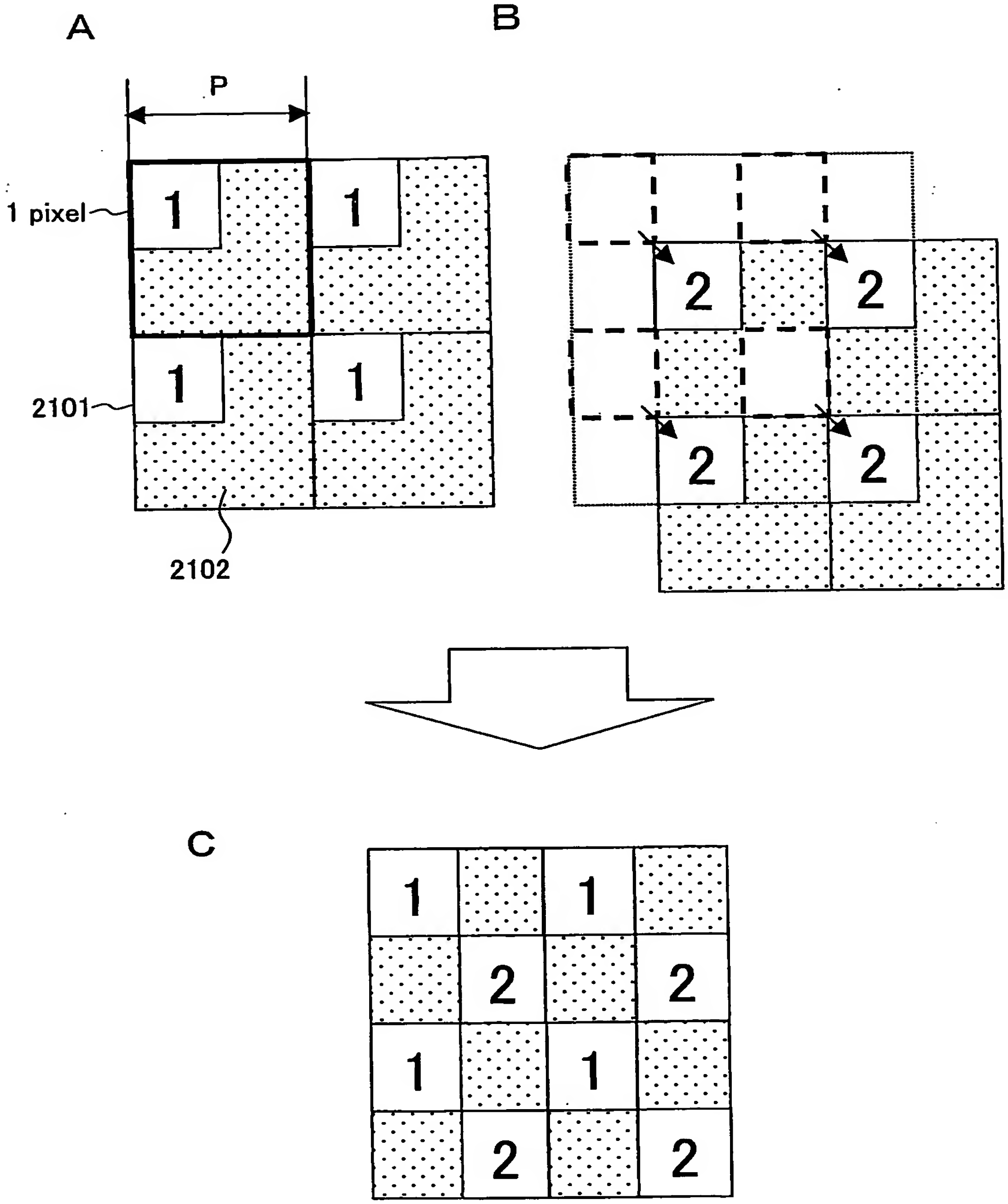
[FIG. 19]


Shift amount
Optical system without pixel shift
Optical system with pixel shift
First image
Second image
Third image

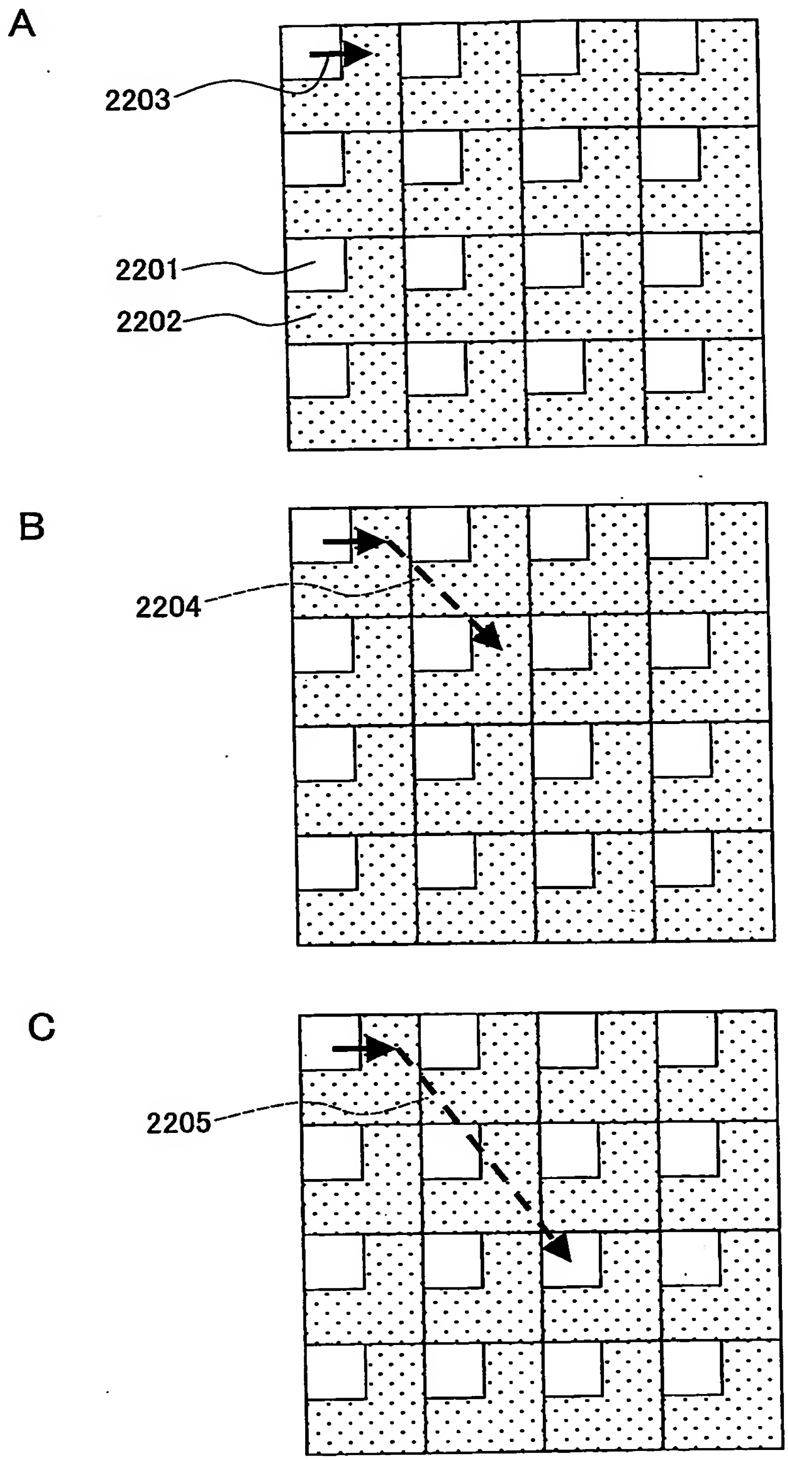
[FIG. 20]


Shift amount
Optical system without pixel shift
Optical system with pixel shift
First image
Second image
Third image
Fourth image
Fifth image

[FIG. 21]



[FIG. 22]



[FIG. 23]